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THE ESSENTIAL GUIDE TO ASTRONOMY

Celestial Celebration

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DECEMBER 2018

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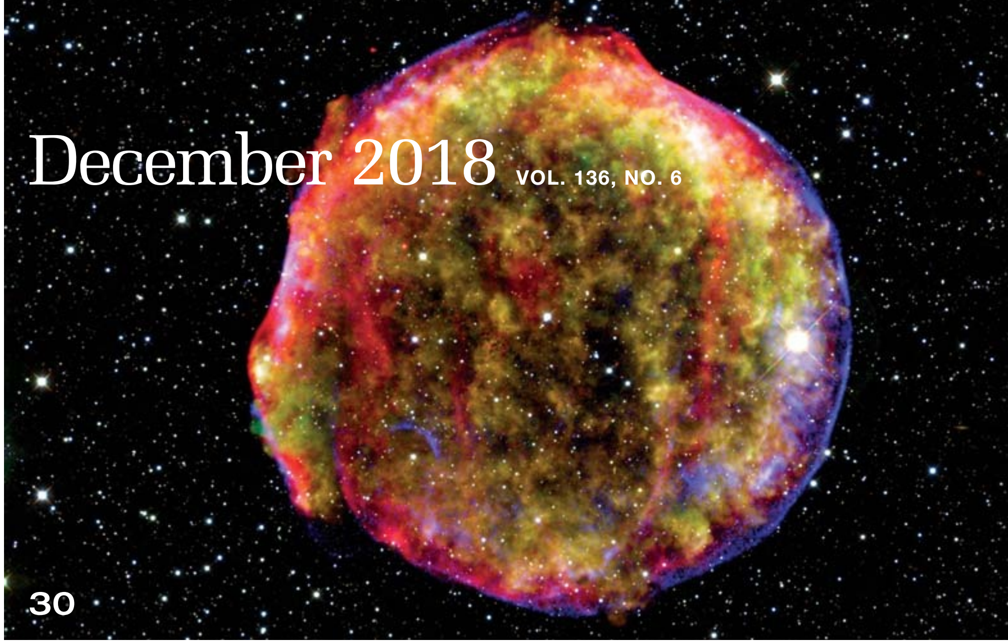

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Mad for the Night

IN THE JULY 1999 ISSUE of *Sky & Telescope*, a new name appeared on the Contributing Editors list. Editor in Chief Leif Robinson introduced this fresh monthly correspondent while announcing a new column premiering in that issue: "Small-Scope Sampler," a tour of the deep sky aimed at users of small telescopes. "Sue French," he wrote, "a well-known amateur and talented writer, will be your guide."

And so she has been for coming on 20 years. For many *S&T* readers, Sue's name has been synonymous with excellence in every aspect of escorting amateur astronomers around the heavens. As Leif's successor Rick Fienberg once wrote, "Sue French offers a rare combination: an encyclopedic knowledge of the night sky, exceptional observing skills, and a transcendent ability to convey the excitement of stargazing through the written word."

Sue French in 1997, the year her first article in *S&T* appeared

Alas, all good things must end. Recently, after turning in her 240th column, Sue emailed me: "I believe this is an auspicious time for me to retire. My eyes, my skies, and my tolerance for cold-weather observing are not what they once were."

What an odyssey it's been. "Small-Scope Sampler" ran until May 2004, when it morphed into "Deep-Sky Wonders." This change was a fitting tribute to Sue's expertise and flair, for that was the title of a beloved column by Walter Scott Houston that *S&T* published from 1946 to 1994. But it also marked a chance for Sue to spread her wings beyond small-scope observing — from binoculars to a 15-inch reflector.

Over the years, we published two collections of Sue's pieces: *Celestial Sampler* came out in 2005 and *Deep-Sky Wonders* in 2011. A taste of her column titles (one of which graces this Spectrum) gives a sense of her personality, wit, and literary style: "A Walk in Starry Mists" . . . "Cuddling Up to the Scorpion" . . . "Stung by Beauty" . . . "Dog Overboard!"

What will Sue do now that she doesn't have to plan everything around the Moon's cycles? "I'll remain an observer," she says, "perhaps doing more sketching and looking at things that almost no one in their right mind would bother with except me." She'll also continue scheduling and attending star parties.

After all that impassioned observing, does she have a favorite celestial object? "I'm rather fond of M11, the Wild Duck Cluster," she says. A favorite column of those 240? "Fireflies," about all you can see in the Pleiades. Her most cherished scopes are her two small refractors, a 105-mm (4-inch) and 130-mm (5-inch). As she told me, "People will have to pry those out of my cold, dead hands."

In the meantime, we wish her all the best in savoring the skies on her own time, in her own way. A huge, collective thank-you, Sue, from the entire *S&T* community.

Editor in Chief

ALAN FRENCH

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The Essential Guide to Astronomy

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Aerial View

Ralph Lorenz's article about viewing impact craters from commercial airplane flights (*S&T:* June 2018, p. 18) took me back to 1993, when I was flying from Harare (Zimbabwe) to Johannesburg (South Africa) and passed over the Pretoria Saltpan, now known as the Tswaing Meteor Crater. The indigenous word *tswaing*, meaning "place of salt," derives from a brine lake on the crater floor that was exploited as a source of soda and salt up until the 1950s.

The crater is about 1,100 meters (3,600 feet) across and 120 meters deep, with a rim height above the surrounding plain of 60 m. Its estimated age is 220,000 years. The brine lake is about 7.5 hectares (19 acres) in area, and its depth is about 3 m. A plaque there honors the late Gene Shoemaker, who pioneered the idea that craters like Tswaing result from impacts.

I have walked around and down into the crater on several occasions — it lies only 40 kilometers (25 miles) north of Pretoria, where I live. It must be one of the more easily accessed impact craters!

Michael Poll
Pretoria, South Africa

▶ Tswaing crater in South Africa, as seen from a plane

MICHAEL POLL

Starting Spectroscopy

I loved the Test Report "Backyard Spectroscopy with *RSpec*" (*S&T:* Sept. 2018, p. 68). The description of the author at the end really piqued my interest: "Rod Mollise enjoys getting some real science out of his time at the telescope."

I recently retired and also would like to do some observing that can really contribute to science. I'm a member of the American Association of Variable Star Observers and the Association of Lunar and Planetary Observers, belong to a local astronomy group, and have access to some very good telescopes. I also have dabbled with some video equipment to capture meteor trails and calculate their trajectory.

I'm prepared to purchase some relatively significant equipment depending on the data to be collected — a very good cooled camera, spectrograph, etc. What I lack are some good ideas and contacts with astronomy researchers who can actually use what I collect.

Shawn Dilles
Vienna, Virginia

Rod Mollise replies: *While both AAVSO and ALPO would likely have interest in the spectroscopic data you collect, a good place to begin when figuring out what to do with your data once you become adept at getting it, is the* RSpec *website,* **rspec-astro.com**, *and the associated mailing list for* RSpec. *There you'll find some great ideas for projects you might undertake once you're up and running.*

I'd also urge you to start simply if you haven't done any work in spectroscopy before. For most of what you'll be doing initially, a cooled camera, for example, isn't required. I found it easier to get started with the little (color) video-type camera described in the article. Later, if you want to go after the really dim stuff — quasars, perhaps — a more sensitive camera might be in order. However, I was amazed at what I could do with my humble ZWO. Also, in the beginning a simple grating like I used for the Test Report is quite adequate.

Eclipse Experiment

I was fascinated by Donald Bruns's article on his replication of Sir Arthur Eddington's famous experiment in starlight deflection during a total solar eclipse (*S&T:* Aug. 2018, p. 22). As a science teacher just starting my career, I'm interested in using the history of this experiment in an upcoming lesson, and I have some questions.

First, in the "Angle of Light" illustration, what do you mean by "Newton's angle = 0.88 arcsecond"? Wouldn't this angle be zero if Einstein's theory was invalid? Second, in the "Deflection Angle" graph, please explain what the blue squares and the round yellow circles specifically represent.

Richard Collins
Georgetown, Massachusetts

Monica Young replies: *Newton considered light to be "corpuscular." In fact, he assumed light had mass, but this really didn't matter. In his equations, which consider a "test particle" with mass m in the presence of a larger body with mass M, the test particle's mass is often irrelevant. For example, to calculate the acceleration of a photon approaching the Sun, you can write out the equation as* $F = GMm/r^2 = ma$. *As you solve for the acceleration (a), the test particle's mass (m) cancels out. For a more detailed explanation of the Newtonian deflection angle, see* **https://arxiv.org/abs/physics/0508030**. *As this article notes, Newton never explicitly discussed a light ray being deflected by a massive celestial body. Einstein did, though, which is what spurred Eddington to make his 1919 solar-eclipse observations in the first place.*

Regarding the graph: The two sets of points show how far stars appear deflected from their true position relative to their distance from the solar limb. The yellow circles represent data collected during an eclipse in 1973. Note that no circles are very close to the Sun, so the researchers weren't able to measure the deflection angle precisely. The blue squares represent data that Dr. Bruns collected during his experiment. He was able to collect data on stars much closer to the solar limb, so he got a more precise measurement of the deflection angle.

Galactic Wanderer

Greg Laughlin's article on `Oumuamua (*S&T:* Oct. 2018, p. 20) leaves me, for the first time in a long life, thinking seriously that this could be something from another civilization. The peculiar light curve, indicating an object very far from spherical, would fit a tumbling space probe of rod or pancake shape. The orbit through our inner solar system is what an alien scientist, curious about those small planets, might choose. When its path to us is calculated back in time, it doesn't lead to any nearby planetary system, but such calculations assume that only gravity was affecting it. A spacecraft would have its own engines, which might have modified its trajectory, particularly if it was an ionic or light-pressure method, as has been proposed for long space missions. That would cause the apparent source to deviate considerably from the real source when the orbit is calculated back.

One scenario to investigate is that this spacecraft got a boost to high velocity by the slingshot method shown in the article, which would work well only if the final velocity vector was near the orbital plane of the planet used. A correction at a right angle to that plane would then be necessary. I would suggest looking for a nearby planetary system whose orbital plane is perpendicular to the path of the object as calculated back.

Jack Ullman
Bronx, NY

Kelly Beatty replies: *A few fast-spinning asteroids do have light curves as dramatic as `Oumuamua's, so it's not impossible that a solid natural, rocky object would have that shape. Also, asteroid expert Alan Harris reminds us that effects such as shadowing and irregular shape can result in light-curve amplitudes that mimic aspect ratios much greater than they actually are. For example, Harris suspects that `Oumuamua might be only three or four times longer than it is wide — far less than the factor of 10 that has been dominating the discussion.*

As the late Carl Sagan often emphasized, "Extraordinary claims require extraordinary evidence."

Open Invitation

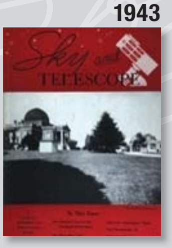
David Nakamoto has done an excellent job describing the history and evolution of the science behind BL Lacertae objects (*S&T:* Sept. 2018, p. 30). Several are visible in large amateur telescopes, and even more can be snagged by imaging. Readers, observers, and imagers are encouraged to partake in the Astronomical League's Active Galactic Nuclei Observing Program (**https://is.gd/AGN_observing**).

Al Lamperti
Oreland, Pennsylvania

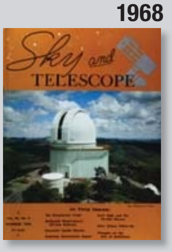
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Roger W. Sinnott

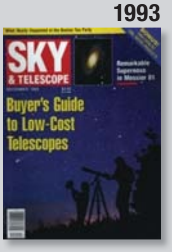
1943



1968



1993



◖ **December 1943**

Exoplanet Quest "The symposium on Dwarf Stars and Planet-like Companions was a most worthy feature of the [American Astronomical Society] meeting. . . . Dr. [Peter] van de Kamp [reported that] Sproul Observatory is making a systematic photographic study of all stars within 10 parsecs (33 light-years) and within reach of the 24-inch refractor. Deviations from uniform (proper) motion are already indicated for several stars. . . .

"Discussion that afternoon was even more active than . . . during the morning, indicating that much more work needs to be done."

More work, and 52 years. Not until 1995 was a Jupiter-size planet confirmed orbiting 51 Pegasi, an ordinary star like our Sun.

◖ **December 1968**

Wise Men's Star "We can readily imagine the ancient scene: As the sun set over the broad Euphrates River, three Babylonian priests made their evening climb up the mammoth ziggurat temple . . . to watch the stars come out.

"In the east the moon was rising, and in the west Venus shone high above the sunset. Just beside it Jupiter could be seen, dimmer and yellower. The priests had been watching the pair for some weeks now, but tonight there was a difference. The two planets were closer together than any one had seen them in many years. As the sky darkened this brilliant 'double star' sank lower, the planets drawing nearer and nearer. At last . . . they fused into one, gleaming like a great beacon over Judea. . . .

"The date was June 17, 2 B.C., and what these Wise Men saw may have been the Star of Bethlehem."

My proposal proved sound in its astronomical details, and many planetariums have recreated it in Christmastime shows. But recent scholarship has veered away from suggestions that the Star was a true spectacle, favoring instead an astrological alignment unnoticed by the general public.

◖ **December 1993**

Pluto's Surface "A team of . . . researchers has discovered that the ices on Pluto's surface are overwhelmingly dominated by nitrogen, not methane. . . . Using high-resolution spectra obtained in May 1992 with the 3.8-meter United Kingdom Infrared Telescope on Mauna Kea, . . . Tobias C. Owen (University of Hawaii) and his colleagues conclude that . . . frozen nitrogen must constitute about 98 percent of the surface ices. . . . The researchers [did find some] methane (CH_4) ice [and] a trace of frozen carbon monoxide (CO). But no evidence exists for water ice or frozen carbon dioxide (CO_2)."

NASA's New Horizons flyby of Pluto in 2015 refined this picture. Along with widespread frozen nitrogen, Pluto has dunes of methane-ice particles. Carbon monoxide ice seems largely confined to the crater-free area of Sputnik Planitia.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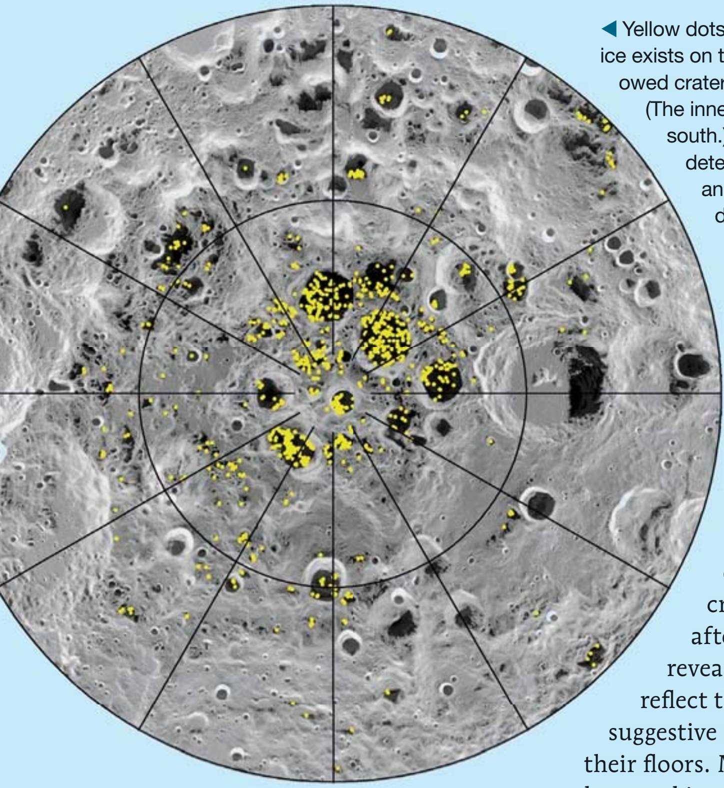


◀ Yellow dots on this map show where water ice exists on the floors of permanently shadowed craters near the Moon's south pole. (The inner black circle marks latitude 85° south.) The dots represent positive detections from multiple instruments: an infrared spectrometer on Chandrayaan 1 together with a laser altimeter, far-ultraviolet mapper, and infrared radiometer on the Lunar Reconnaissance Orbiter.

SOLAR SYSTEM

Solid Evidence of Water Ice on Moon

AFTER MORE THAN A DECADE of tantalizing but inconclusive hints, new research shows convincingly that patches of water ice lie exposed on the floors of many permanently shadowed lunar craters. Shuai Li (University of Hawai‘i) and colleagues make use of near-infrared spectra from India's Chandrayaan 1 orbiter, which operated between 2008 and 2009, and report the findings in the September 4th *Proceedings of the National Academy of Sciences*.

Water ice can remain inside these craters because their floors are never exposed to direct sunlight, the consequence of a lunar spin axis that's nearly (within 1½°) perpendicular to the ecliptic plane. Temperatures at these always-dark crater floors are extremely low, plunging as low as 40K (–390°F). Any local traces of water vapor — delivered, say, by a small comet's impact — will freeze out in these "cold traps" and remain there.

Earlier observations had supported water ice deposits inside these craters, but the evidence had been indirect. For example, as early as 1994, radar pulses fired from the orbiting Clementine spacecraft and recorded on Earth after bouncing off the Moon revealed that some polar craters reflect the radio energy strongly, suggestive of water ice sequestered on their floors. More recently, images from lunar orbiters have shown that the polar craters' shadowed floors are relatively bright at ultraviolet and near-infrared wavelengths. But "bright" doesn't automatically translate to "ice" — other explanations are possible.

Another strong piece of evidence came from a spectrometer on NASA's Lunar Reconnaissance Orbiter that counted neutrons emitted from the lunar poles within a specific energy range, which signifies interaction with hydrogen atoms and thus, most likely, water. But this instrument can't distinguish water molecules (H_2O) from their chemical relative hydroxyl (OH), which readily binds to rocky minerals. Also, the neutrons could have come from the surface or from depths of up to a few tens of centimeters (up to a foot).

The work of Li and colleagues sidesteps all of these ambiguities by looking for three specific near-infrared absorptions — near 1.3, 1.5, and 2.0 microns — created by vibrations in water ice molecules lying directly on the lunar surface. They carefully examined spectral maps made by Chandrayaan 1's Moon Mineralogy Mapper, or M^3, and found that regions featuring absorption at all three wavelengths correspond to permanently shadowed crater floors at both lunar poles.

Modeling suggests that this three-band technique is sensitive enough to identify surface deposits heavily mixed with the dust and rocks that make up lunar "dirt," containing as little as 5% water ice by weight. The M^3 spectra only signal the presence of water in craters poleward of latitude 70°, and 90% of the positive detections occur within 10° of each pole.

Understanding the processes that delivered water ice to the Moon helps us understand the origin of water on Earth and throughout the solar system, Li explains. Of course, knowing that water ice lies exposed at the lunar poles is also a big plus in the minds of those designing future lunar colonies.

■ **J. KELLY BEATTY**

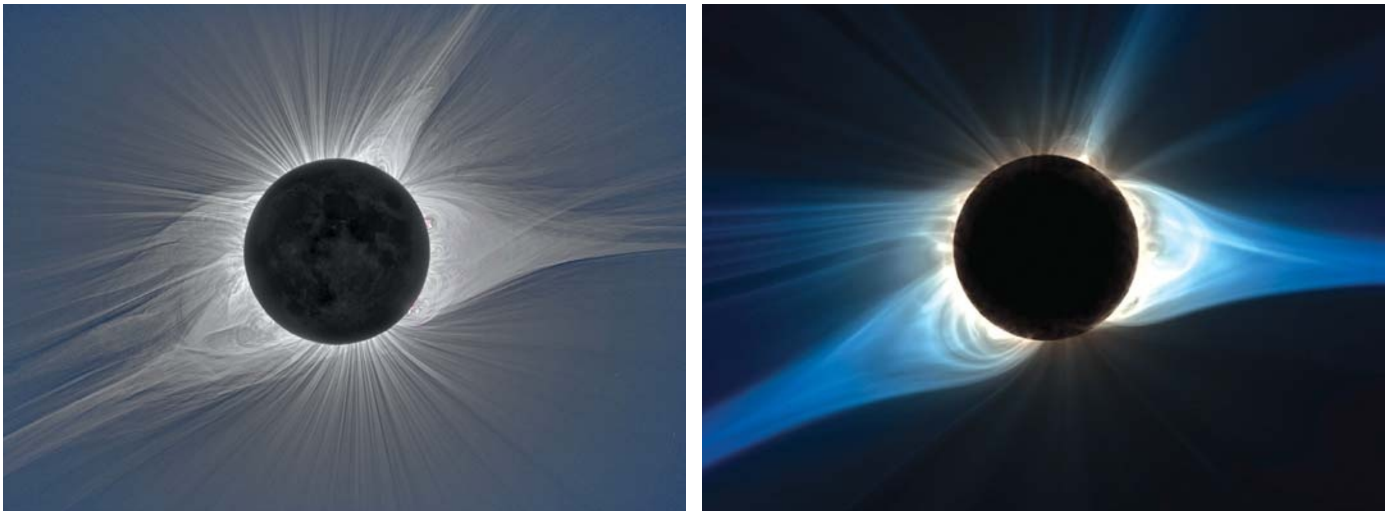
EXOPLANETS

Astronomers "Weigh" Beta Pictoris b

ASTRONOMERS HAVE OBTAINED a precise new mass measurement for Beta Pictoris b, a gas-giant planet 63 light-years from Earth. Ignas Snellen and Anthony Brown (both at Leiden University, The Netherlands) reported the measurement August 20th in *Nature Astronomy*.

The exoplanet came to light in 2008, when the European Southern Observatory's Very Large Telescope in Chile captured the infrared glow of the planet still in the throes of formation. But in the decade since, astronomers have been struggling to nail down the planet's detailed properties, especially its mass. They suspected the planet has a mass several times that of Jupiter, due to its influence on the star's large debris disk. Later mass estimates based on direct imaging ranged from 4 to 17 times Jupiter's mass.

Now, Snellen and Brown have used exquisite positional data from the Hip-



SOLAR ECLIPSE

Scientists Successfully Predict Shape of Solar Corona

▲ An enhanced photograph of totality (*left*) compares well to the simulated view (*right*).

SCIENTISTS ATTEMPTED TO predict the shape of the Sun's corona as it would appear during the total solar eclipse on August 21, 2017. Observations confirmed that they got the broad strokes right.

The corona, an intricate crown of thin, super-hot plasma around the Sun, expresses our star's hidden magnetic angst. Its charged particles respond to the magnetic field by twisting into loops, bands, and even erupting into interplanetary space. Solar physicists led by Zoran Mikić (Predictive Science) report August 27th in *Nature Astronomy* that they can accurately predict the appearance of the corona one week in advance — an important milestone on the path to predicting the oncoming solar wind.

The team offered a new model of the Sun's outer layers that takes into account how their heat and magnetic fields stimulate the corona. Using observations of the Sun taken on July 16 and August 11, 2017, as a baseline, Mikić and colleagues ran a simulation on a NASA supercomputer to calculate the solar corona's appearance 10 days later. They then compared these visualizations to images taken by ground-based photographers during totality.

Encouragingly, the simulated corona has the same general shape as its real-life counterpart, with a few bold, bright plasma "streamers" flowing out into space, as well as intervening loops similar to those seen dancing in the images.

The simulated Sun doesn't perfectly mimic the corona's finer features, but its large-scale correspondence gives solar astronomers confidence that they're on the right track to understanding the physics of the Sun's outer layers. It also enables them to test their ideas of solar physics. With improved measurements of solar magnetic fields, such as those expected from NASA's Parker Solar Probe (*S&T:* Nov. 2018, p. 9), models like this one could soon track the Sun's evolution and potentially improve space weather forecasts, the authors conclude.

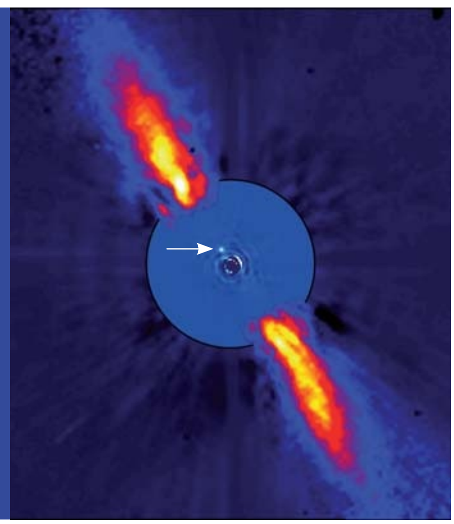
■ **EMILY SANDFORD**

ECLIPSE PHOTO: MILOSLAV DRUCKMÜLLER / PETER ANIOL / SHADIA HABBAL; ECLIPSE SIMULATION: PREDICTIVE SCIENCE; BETA PICTORIS B: ESO / A-M. LAGRANGE ET AL.

parcos and Gaia missions to measure the star's wobbles on the sky, due to the planet's gravitational tugs on its host. Unlike previous estimates, the new result doesn't depend on assumptions about the star or disk. The astronomers pinned Beta Pictoris b's mass to between 9 and 13 times that of Jupiter. Snellen and Brown used the same measurements to conclude that the planet takes at least 22 years to circle its star.

While there are many observations of disks that have yet to form planets and thousands of known planetary systems, the number of known, still-forming planets is small. As one of the youngest directly imaged planets, Beta Pictoris b provides a vital data point in understanding how young gas giants accumulate material. Moreover, Gaia data may help astronomers investigate many more planets in the same way.

■ **JOHN BOCHANSKI**



▶ The planet Beta Pictoris b (arrowed) is visible orbiting its host star in this composite image from the European Southern Observatory's 3.6-m telescope and the NACO instrument on the ESO's 8.2-m Very Large Telescope.

STARS

Sibling Rivalry Incited Eta Carinae's Explosion

NEW ANALYSIS OF THE MASSIVE Eta Carinae star system supports the idea that the system once had three stars — but only two survived.

Eta Carinae experienced its so-called Great Eruption about 170 years ago: a blast that resembled a supernova in ferocity but left the massive primary star intact (*S&T:* Oct. 2016, p. 26). Now, a pair of studies appearing in the October *Monthly Notices of the Royal Astronomical Society* have tracked down faint reflections of the explosion's light as it scatters off of nearby interstellar dust. The roundabout path of the *light echo* gives astronomers a real-time view of the long-ago goings-on.

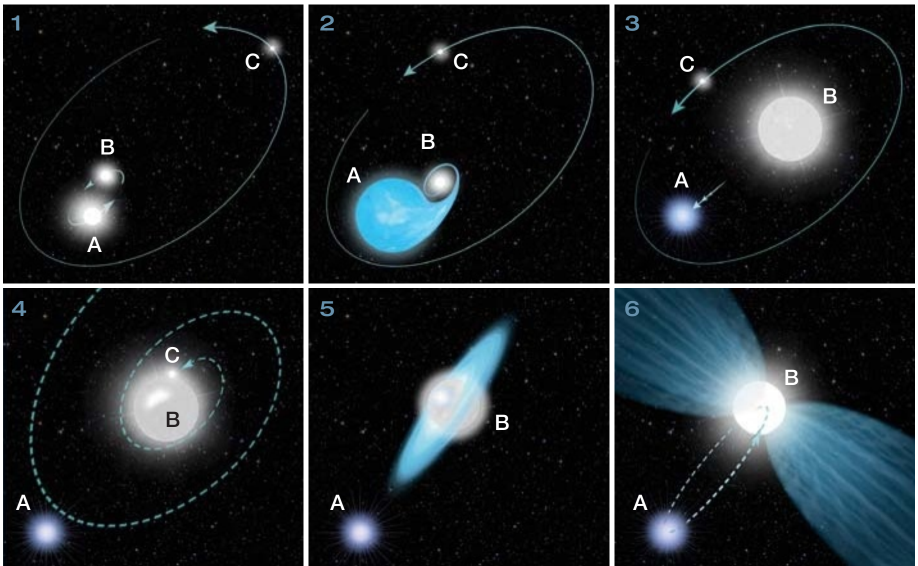
By taking a spectrum of the reflected light, Nathan Smith (University of Arizona) and colleagues measured the speed of material at different stages of the explosion. The first phase showed relatively sedate debris that moved between about 150 to 600 km/s (340,000 to 1 million mph). Later, the motions accelerated, but unevenly: Earthward-pointing winds reached 10,000 km/s; winds on the opposite side moved even faster at 20,000 km/s.

The team suggests that a violent interaction between three stars could explain these observations. In this scenario, two stars (A and B) initially orbited each other closely, while a third star (C) circled the pair farther out. As A reached the end of its life, it lost its outer layers, transferring mass to B. As B grew bigger than A, to at least 100 Suns, the system's center of mass shifted toward B. This change caused A's orbit to widen, so it eventually interacted and swapped places with C.

However, B and C's mutual orbit wasn't stable and they spiraled inward. They shed mass in this first, slower phase of the eruption and surrounded the system in a cocoon of dense, slowly expanding gas. Once merged, they triggered an explosion that slammed stellar material into this cocoon, releasing the tremendous energy seen in the Great Eruption and reproducing the multiple debris speeds recorded in the light echoes' second, faster phase.

Smith's team plans to continue monitoring existing light echoes, as well as search for more, to provide additional information about how the explosion changed over time.

■ ELIZABETH HOWELL



▲ This graphic illustrates a complex merger scenario that could explain Eta Carinae's Great Eruption in the mid-1800s.

BLACK HOLES

Middleweight Black Holes Shed Light on Early Universe

SUPERMASSIVE BLACK HOLES — typically ranging in mass from millions to billions of Suns — already existed by the time the universe had reached a billion years old (*S&T:* Jan. 2017, p. 24). How did these cosmic beasts grow so quickly? Two studies attempting to answer this question have discovered dozens of middling-mass black holes in nearby dwarf galaxies, adding fuel to an ongoing debate.

Supermassive black holes might have grown out of the collapse of the first generation of stars, which would have given birth to 100-solar-mass "seeds." The abundance of early stars means this kind of seed would have been common. As a result, most present-day dwarf galaxies should host massive (although not supermassive) black holes.

Alternatively, huge gas clouds might have collapsed directly into much more massive black hole seeds. This scenario would have required special conditions, so it probably didn't happen as often. In this case, nearby dwarf galaxies should only rarely host massive black holes.

Mar Mezcua (Institute of Space Sciences, Spain) and colleagues pored through the Chandra COSMOS Legacy Survey to find 40 dwarf galaxies with actively feeding, middleweight black holes. The team used this fraction of *active* black holes — roughly 10% — as a proxy for the *total* fraction of black holes, arguing in the August 1st *Monthly Notices of the Royal Astronomical Society* that the low number favors the latter, direct-collapse model.

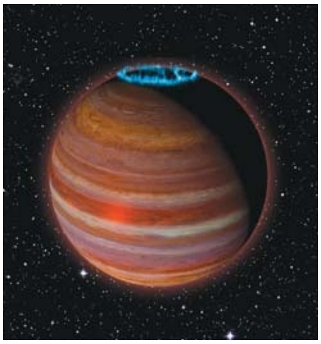
NASA / ESA / A. FEILD (STSCI)

STARS

Auroras Discovered Around Rogue Brown Dwarf

ASTRONOMERS HAVE DISCOVERED auroras around a set of brown dwarfs — including a "rogue" that wanders the galaxy alone — indicating surprisingly strong magnetic fields in these failed stars.

Melodie Kao (Arizona State University) and colleagues used the Karl G. Jansky Very Large Array to detect high-frequency radio emissions from five nearby brown dwarfs, with masses between 12 and 30 times the mass of Jupiter. Among these is SIMP 0136+0933, a possible planet with 13 times Jupiter's mass, floating on its own in interstellar space about 20 light-years away. The emissions indicate that the five objects' magnetic fields are hundreds to thousands of times stronger than those around the Sun, powering brilliant, radio-emitting aurorae similar to the northern lights on Earth. The results appear in the August *Astrophysical Journal Supplement Series*.



▲ Artist's conception of the rogue SIMP 0136+0933

Aurorae happen when charged particles from the Sun stream in along Earth's magnetic field and crash into our upper atmosphere. A similar mechanism works at Jupiter but with particles coming from the planet's moons rather than the Sun. Since SIMP 0136+0933 has no host star, its aurorae can't come from interactions with a stellar wind. Perhaps it hosts a moon of its own, but before scientists can come to that conclusion, more observations are needed to confirm the origin of its radio waves.

The sheer intensity of the dwarfs' radio emissions poses its own puzzle, presenting "huge challenges to our understanding of the dynamo mechanism that produces the magnetic fields in brown dwarfs and exoplanets," says coauthor Gregg Hallinan (Caltech).

When Kao and her team closely examined SIMP 0136+0933 and the other brown dwarfs, they found they couldn't easily relate their magnetic field strengths to the objects' masses, temperatures, or ages. This implies that the generation of strong magnetic fields in these objects is probably much different than the mechanisms that create fields in the Sun or Earth.

■ JOHN BOCHANSKI

But not all black holes are active. It could be that huge numbers of mass-starved black holes, silent in X-rays, lurk undetected in other dwarfs; thus the result can't rule out the stellar-seed scenario just yet.

Igor Chilingarian (Smithsonian Astrophysical Observatory) and colleagues added to the debate when they used X-ray observations to confirm 10 black holes (out of a larger sample of 305 candidates) with between 36,000 and 370,000 Suns' worth of mass in nearby dwarf galaxies. Their results appear in the August 10th *Astrophysical Journal*. Chilingarian contends that the mere existence of black holes on the lower end of this mass spectrum favors the stellar-seed scenario. Mezcua counters that direct-collapse models are flexible enough to allow for masses that small.

Ultimately, only knowing the true number of black holes in dwarf galaxies will settle the debate. But in the meantime, the trove of new middleweight black holes will enable astronomers to investigate trends in their growth and evolution.

■ MONICA YOUNG

CALTECH / CHUCK CARTER / NRAO / AUI / NSF

IN BRIEF

Upgrade for Arecibo Observatory

The iconic Arecibo Observatory has received a recent boost in funding — $5.8 million from the National Science Foundation — to help design and build a new receiver, which will be installed in 2022. Called a *phased-array feed*, the receiver consists of 166 antennas that will increase the telescope's field of view and boost its survey speed, making it five times faster than it is now. A major goal for the new instrument is to find and monitor millisecond pulsars, whose minute variations help measure the low-frequency hum of gravitational waves suffusing the universe. Find more on how the observatory fared post-hurricane at **https://is.gd/AreciboUpgrade**.

■ ELIZABETH HOWELL

AAS Opens Membership to Amateurs

The American Astronomical Society (AAS) began as an organization of both professionals and amateur astronomers. Now, the society is returning to that foundation by opening membership to amateurs via its Amateur Affiliate Program. Dues are $52 for 2019; inaugural benefits will include reduced registration fees for AAS meetings and access to AAS journals. Additional opportunities are expected once a critical mass is established. To learn more and join, go to **https://is.gd/AASamateur**.

■ MONICA YOUNG

Impact Shaped Ice Giant

Scientists have long known that a long-ago impact likely caused Uranus's strange tilt. Jacob Kegerreis (Durham University, UK) and colleagues explore this concept further by simulating more than 50 impact scenarios. In the July 1st *Astrophysical Journal*, the team concludes that 4 billion years ago, a rock-and-ice protoplanet with at least twice Earth's mass collided with Uranus and knocked it over. But the planet held on to most of its gaseous atmosphere; what little gas it lost might have helped form the thin rings that encircle the planet today. The ancient collision helps explain why the ice giant's atmosphere is so incredibly cold (57 K, or –357°F), even for being so far out from the Sun: The simulations suggest that the impactor's debris formed a thin shell of ice within Uranus that traps heat emanating from the planet's core. The impact could also explain the planet's tilted and off-center magnetic field. Read more at **https://is.gd/icegiantimpact**.

■ MONICA YOUNG

MONSTE SCIENCE

The next generation of superscopes will have truck-size instruments and universe-size science projects.

In two feature articles, S&T Contributing Editor Govert Schilling looks into the future of optical and near-infrared ground-based astronomy. Last month's article described the next generation of extremely large telescopes; this month's story focuses on the outstanding science questions they will explore.

"It's difficult to make predictions, especially about the future." This quote, which has been attributed to Niels Bohr, Mark Twain, and Yogi Berra, among others, is particularly true of the development of astronomy. In their exploration of the universe, humans continuously stumble upon unexpected discoveries and insights.

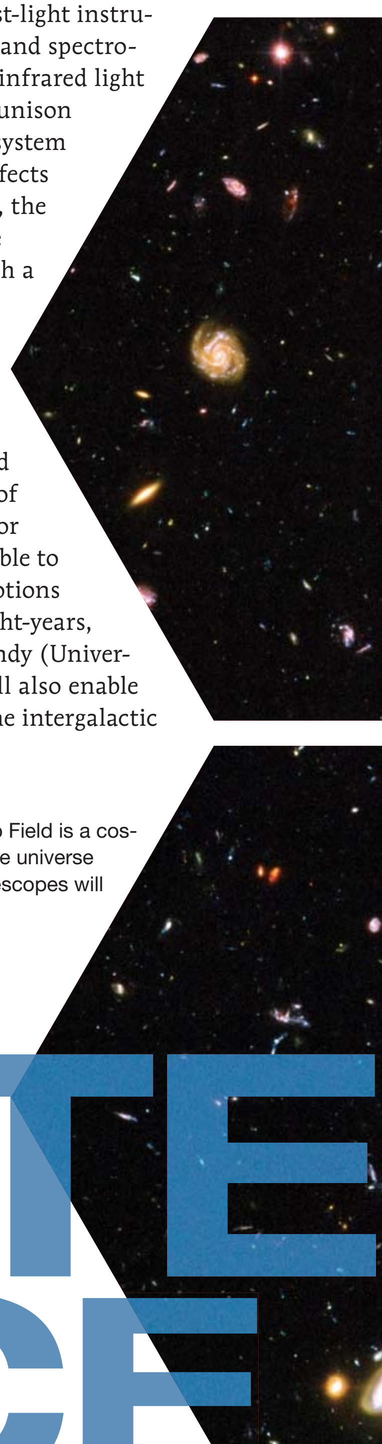
Still, you can't make progress without some form of preparation. If you design a new generation of extremely large telescopes, you have to think about the scientific riddles you want to solve and about the best way to tackle the accompanying challenges. So what do astronomers hope to learn, and how do they plan to achieve their goals?

Over the past few years, large international working groups for the three monster telescope projects of the 2020s — the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT), and the Extremely Large Telescope (ELT) — have prepared comprehensive inventories of the scientific questions their instruments are expected to address. These so-called science cases, which are freely available for download, comprise 202, 204, and 772 pages for the TMT, GMT, and ELT, respectively. In general, the three future telescopes plan to focus on the same scientific spearheads: cosmology, galaxy evolution, fundamental physics, the origin of stars and planets, exoplanets, and solar system science. Yes, that's about all of astronomy — the telescope giants of the next decade will be as versatile as the Hubble Space Telescope has been, which of course is a good thing for billion-dollar projects.

But without their suites of instruments and detectors, the megascopes would all be blind: If a huge telescope mirror is the "lens" of a giant eye on the cosmos, the observational instruments constitute the retina. All three telescopes will be outfitted with a small number of first-light instruments (see box, page 18) — cameras and spectrographs that collect optical and near-infrared light from stars and galaxies, working in unison with the telescope's adaptive optics system that compensates for the blurring effects of atmospheric turbulence. Together, the telescopes and their instruments are expected to provide astronomers with a revolutionary new view of the universe we live in.

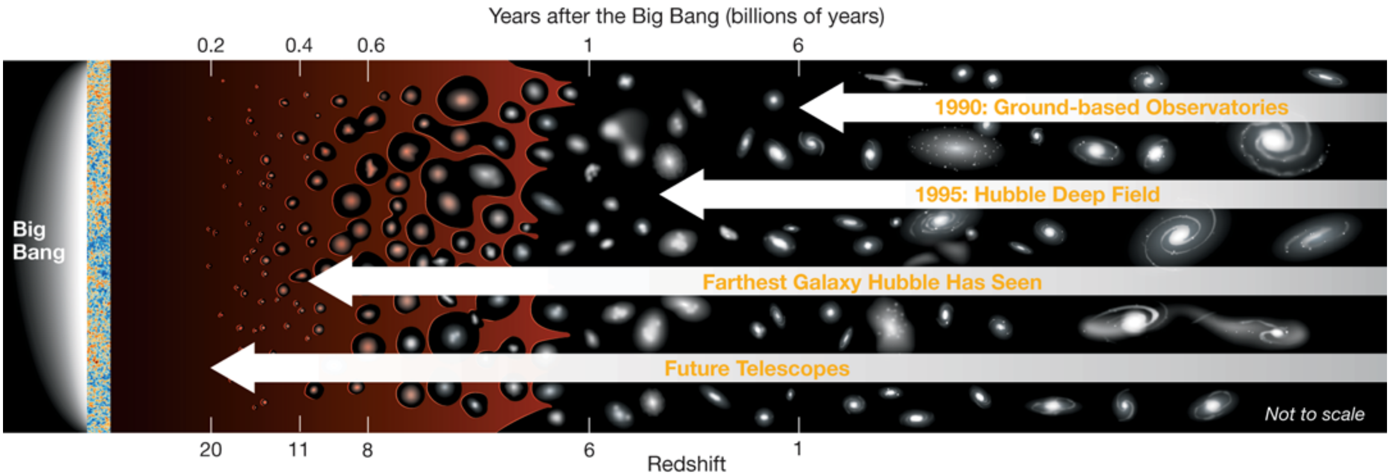
Colossal Retinas

Expectations for these instruments are high. For example, the Wide Field Optical Spectrometer (WFOS), one of the scientific instruments planned for the Thirty Meter Telescope, will be able to study the chemistry and internal motions of galaxies out to some 10 billion light-years, says principal investigator Kevin Bundy (University of California, Santa Cruz). It will also enable astronomers to create 3D maps of the intergalactic medium.



▶ **INTO THE DEEP** The Hubble Ultra Deep Field is a cosmic "core sample," drilling back to when the universe was some 800 million years old. Future telescopes will peer 600 million years earlier.

NASA / ESA / S. BECKWITH (STSCI) / HUDF TEAM



▲ **EARLY UNIVERSE** By building larger telescopes and looking at longer wavelengths, astronomers are seeing earlier and earlier in cosmic time. Currently, the earliest infant galaxies are those seen as they were less than a billion years after the Big Bang. But the GMT, TMT, ELT, and JWST will push even further, to when the first stars and galaxies formed.

On the exoplanet front, instruments such as the GMT-Consortium Large Earth Finder (G-CLEF) and the Mid-Infrared ELT Imager and Spectrograph (METIS) may be able to detect so-called biomarkers — chemicals that would suggest the presence of extraterrestrial life — in the atmospheres of nearby Earth-like exoplanets. “METIS is going to be a killer instrument for exoplanets,” says principal investigator Bernhard Brandl (Leiden University, The Netherlands). That’s partly because of its high spectral resolution of 100,000 in the mid-infrared: At a wavelength of 3 microns, for example, the instrument will be able to resolve spectral features as small as 0.03 nanometer.

▼ **A GIANT AMONG MEN** This preliminary ELT schematic shows the scales involved in the three telescopes’ instruments (representative structures shown on platforms). Notice the people included for scale on the platform and ground.

But it’s not going to be easy (or cheap) to build and operate this new generation of astronomical detectors. Current instruments are already huge. The European Southern Observatory’s Multi Unit Spectroscopic Explorer (MUSE) instrument at the Very Large Telescope measures a few meters across. The 570-megapixel Dark Energy Camera (DECam), which sits at the 4-meter Blanco Telescope at the Cerro Tololo Inter-American Observatory in Chile, weighs in at 4 tons. But a much larger telescope aperture also means a much larger focal plane, explains Bundy. “In the case of the TMT, the focal plane is about 2 meters wide — it’s as large as a barn door.” As a result, the instruments for the new megascopes also need to be humongous. “WFOS is the size of a large cargo truck and will weigh 40 tons or so.”

Moreover, explains G-CLEF principal investigator Andrew Szentgyorgyi (Harvard-Smithsonian Center for Astrophysics), the huge size and weight of the new instruments will make it hard to retain the necessary optical stability. During observations, major parts of any astronomical instrument need to rotate to compensate for the diurnal motion of the sky, and even the slightest gravitational flexure would compromise the measurements. To cope, instruments need to be constructed of light materials with high tensile strength. “That’s why the optical bench of G-CLEF will be made of carbon fiber epoxy instead of steel,” says Szentgyorgyi. According to Brandl, the European METIS instrument will even have its own internal version of adaptive optics to meet the stability requirements.

Cosmological Challenges

Work with Hubble has laid the foundation for what the coming megascopes will discover about the early universe. Thanks to the bonus magnification of gravitational lensing by foreground clusters, Hubble has shown us galaxies so remote that the light we see today was emitted when the universe was about half a billion years old. We know that these very early proto-galaxies formed from slight overdensities in the primordial cosmic brew of dark matter, hydrogen, and helium — overdensities that, in turn, resulted from quantum fluctuations immediately after the Big Bang. Hubble has proven itself to be a successful cosmic archaeologist.

But the early universe is still shrouded in riddles. "The major challenges are many," says cosmologist Richard Ellis (University College London). "If I had to choose one, it is determining the period when galaxies switched on — the so-called period of *cosmic dawn* — and understanding how these early galaxies built up their stars and black holes. In many ways this is now the final frontier in piecing together a coherent picture of cosmic history."

Recent radio observations of neutral hydrogen gas in the very early universe (*S&T:* June 2018, p. 8) suggest that the first stars and proto-galaxies emerged from the darkness when the universe was only 180 to 250 million years old. But finding and studying these very first objects is extremely challenging. The superior light-gathering power of the ELT will naturally be an advantage here. These early sources are also very compact, so adaptive optics, which features prominently in the instrument suites of all three future observatories, will be helpful, says Ellis. "My personal hope, within my lifetime, is that the two independent routes — age-dating early galaxies and radio studies of the gas in space — will harmoniously meet with the same conclusion."

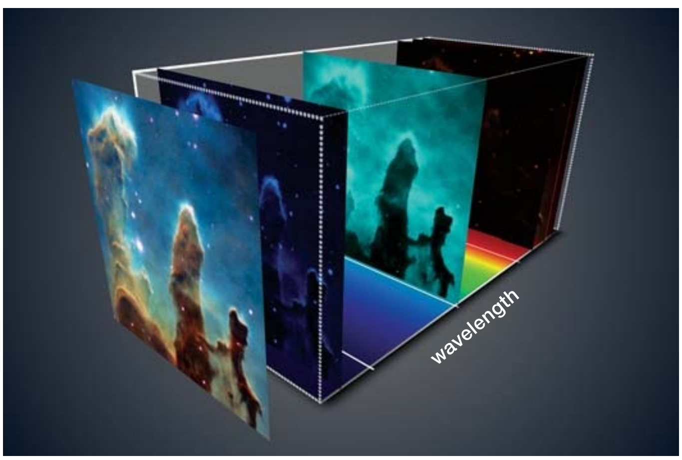
Rychard Bouwens (Leiden University), who studies the very earliest galaxies in the universe, is also interested in star-formation rates in these young systems. "At the highest redshifts, there is some evidence that stars form more efficiently for a given amount of dark matter than at later times," he says. He also wants to know how quickly stars built up the level of elements heavier than helium, and what the properties were of the most pristine stars in the early universe before that happened.

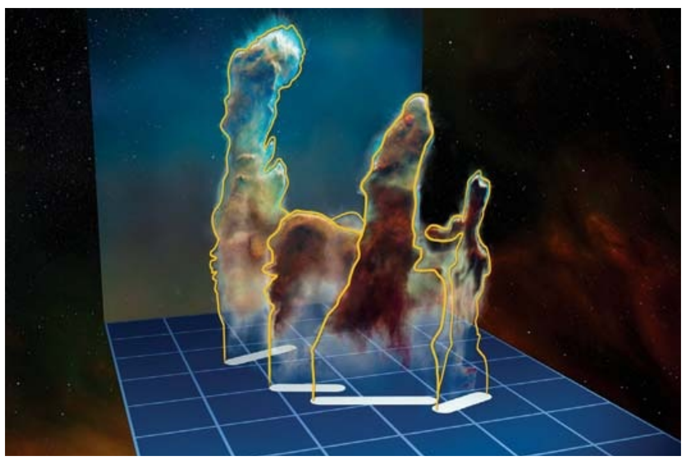
"Determining the period when galaxies switched on . . . is now the final frontier in piecing together a coherent picture of cosmic history."

~Richard Ellis

In addition, Bouwens notes there's still much uncertainty about the formation of globular clusters — spherical collections of hundreds of thousands of stars that are thought to be among the oldest cosmic structures. The upcoming high-resolution imaging spectrographs are designed to tackle these questions, partly by using a technique known as *integral-field spectroscopy* (IFS), in which a spectrum is obtained for each and every pixel in the instrument's field of view. The combined characteristics of the Extremely Large Telescope and its METIS instrument will, for the first time ever, enable the combination of IFS with high-resolution spectroscopy, says Brandl.

Both Ellis and Bouwens stress the importance of synergy between the next generation of ground-based telescopes and future instruments in space. These include the delayed James Webb Space Telescope (*S&T:* Oct. 2018, p. 11), which won't be hampered by the thermal infrared glow of Earth's atmosphere, and the European Space Agency's Euclid mission, with its much larger field of view. Euclid's all-sky survey will be essential for finding the most luminous and rarest galaxies, says Bouwens. "The power of JWST will be its ability to obtain infrared spectra of distant galaxies, while the resolving power of future extremely large telescopes will be most useful for spatially resolving distant star-forming sources." To give an idea: With adaptive optics, the Extremely Large Telescope will achieve an angular resolution of less than 10 milliarcseconds in the near-infrared part of the spectrum. That's how big a semi-truck would look at the distance of the Moon.





▲ **UNIVERSE IN 3D** By taking a spectrum of each pixel, integral-field spectroscopy (IFS) reveals what the object looks like at different wavelengths, providing information about composition, motion, and structure. IFS observations of the iconic Pillars of Creation show that the pillars are actually several distinct pieces. (Distances are not to scale.)

ESO (2)

Indirectly, the new instruments will also help to solve the nagging problem of the composition of the universe. Various lines of evidence indicate that baryonic matter (essentially, atoms) constitute at most 5% of the matter/energy content of the universe. The remainder is in the form of dark matter and dark energy, the true nature of which is frustratingly unknown. Thanks to their exquisite resolution and sensitivity, extremely large telescopes will be able to study the distribution of dark matter in tiny dwarf galaxies and to reveal small-scale substructure in the distribution of dark matter in the vast cosmic web through gravitational lensing.

As for dark energy: Observations of supernova explosions in the most distant galaxies will help establish the expansion history of the universe, which is ultimately dictated by the subtle balance between the attractive gravity of dark matter and the repulsive "anti-gravity" of dark energy (*S&T:* May 2018, p. 14). Moreover, ELT scientists hope to be able to measure the resulting accelerated expansion of the universe *directly*, independent of assumptions about the large-scale curvature of spacetime and cosmological models. Thanks to the accelerated expansion, the apparent recession velocity of distant quasars (which is a substantial fraction of the speed of light) should increase with a few centimeters per second over a decade, slightly increasing the object's redshift. The huge light-collecting power of the ELT, together with new developments in quantum optics, should enable astronomers to actually measure this tiny redshift drift. Such a unique measurement would constitute the first direct evidence of accelerated expansion and would certainly help in solving the mystery of dark energy.

High-resolution spectra of remote quasars may also provide an answer to yet another nagging question: Are the constants of nature really constant, or do they slowly change with time? In particular, the *fine structure constant* (α) — a measure of the strength of the electromagnetic interaction

NGC 4650A: ESO / MUSE CONSORTIUM / R. BACON;
WAVELENGTHS: TERRI DUBÉ / S&T

▼ **COLOR-CODED GALAXY** Using the MUSE integral-field spectrograph on the Very Large Telescope, astronomers created this color composite of the polar ring galaxy NGC 4650A. The colors represent the velocities of star-forming regions due to the rotation of the galaxy's disk: Blue regions are approaching, red regions receding.

First-generation Eyes

Listed are instruments currently slated to be part of the first-light package. Astronomers are already discussing second-generation instruments. Wavelength ranges and fields of view are not final, as some teams are still considering design options.

THIRTY METER TELESCOPE (TMT)

1. WFOS (Wide Field Optical Spectrometer)

Near-ultraviolet and optical wide-field multi-object imager and spectrograph

Wavelength range:
0.31 – 1 μm

Field of view:
~10 arcmin diameter

2. IRIS (Infrared Imaging Spectrometer)

Near-infrared adaptive optics-fed integral field imager and spectrograph

Wavelength range:
0.8 – 2.5 μm

Field of view:
32 × 32 arcsec (imager)

EXTREMELY LARGE TELESCOPE (ELT)

1. MICADO (Multi-AO Imaging Camera for Deep Observations)

Near-infrared adaptive optics-fed imaging camera and spectrograph

Wavelength range:
0.8 – 2.4 μm

Field of view:
50.5 arcsec × 50.5 arcsec

2. HARMONI (High Angular Resolution Monolithic Optical and Near-infrared Integral Field Spectrograph)

Near-infrared integral-field spectrograph

Wavelength range:
0.47 – 2.45 μm

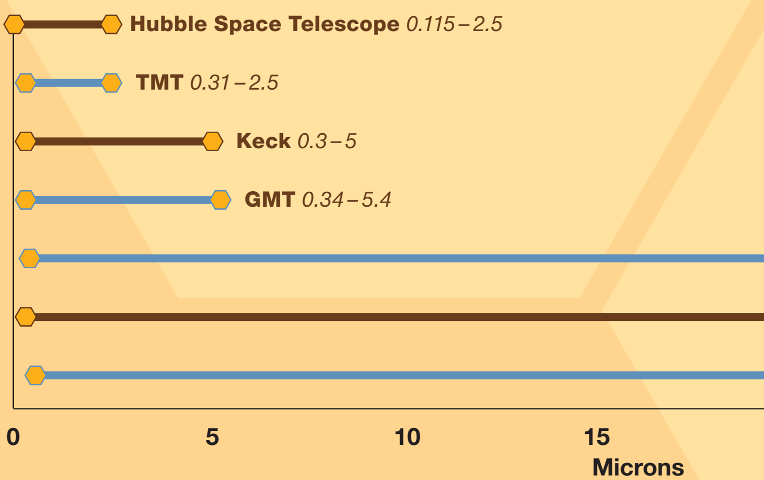
3. METIS (Mid-Infrared ELT Imager and Spectrograph)

Mid-infrared imager (with coronagraphic capability) and medium-resolution spectrograph

Wavelength range:
3 – 20 μm

Field of view:
17.6 × 17.6 arcsec

▼ **WAVELENGTH RANGES** Astronomers are pushing into the infrared (about 1 to 1,000 microns, or 1,000 to 1 million nanometers) with both current and future telescopes. In part, that's because light reaching us from the first galaxies has redshifted to this range. But infrared wavelengths are also good for peering through dust; detecting cool, red stars; studying planet-forming disks; and observing bodies in our solar system. Blue indicates future telescopes.



JAMES WEBB SPACE TELESCOPE (JWST)

1. NIRCam (Near-Infrared Camera)

Near-infrared imager with coronagraphic capability and slitless "grism" spectroscopy

Wavelength range:
0.6–5 μm

Field of view:
2.2 × 2.2 arcmin (each of two fields)

2. NIRSpec (Near-Infrared Spectrograph), *European contribution*

Near-infrared multi-object spectrograph (through microshutter array technology)

Wavelength range:
0.6–5 μm

Field of view:
3.4 × 3.6 arcmin

3. MIRI (Mid-Infrared Instrument), *European and U.S. contribution*

Mid-infrared camera and medium-resolution spectrograph

Wavelength range:
5–28 μm

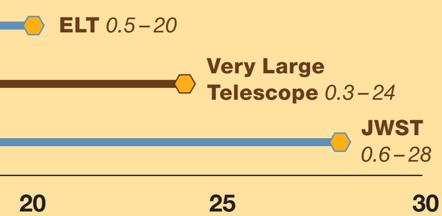
Field of view:
1.2 × 1.9 arcmin (imager)

4. FGC/NIRISS (Fine Guidance Sensor/Near Infrared Imager and Slitless Spectrograph), *Canadian contribution*

Precision pointing for high-quality imaging and slitless spectroscopy

Wavelength range:
0.8–5 μm

Field of view:
2.2 × 2.2 arcmin



GIANT MAGELLAN TELESCOPE (GMT)

1. ComCam (Commissioning Camera)

Used to validate the adaptive-optics performance and initial telescope alignment. Also available for deep imaging.

Wavelength range:
0.34–0.95 μm

Field of view:
7 arcmin × 7 arcmin

2. G-CLEF (GMT-Consortium Large Earth Finder)

Fiber-fed high-resolution visible-light echelle spectrograph with radial velocity capabilities

Wavelength range:
0.35–0.95 μm

Field of view:
Up to 20 arcmin diameter (when connected to fiber-optics system)

3. GMACS (GMT Multi-Object Astronomical and Cosmological Spectrograph)

Moderate-resolution visible multi-object spectrograph, with fiber-optics capabilities

Wavelength range:
0.35–1 μm

Field of view:
Up to 20 arcmin diameter (with fiber optics system)

4. GMTIFS (GMT Integral-Field Spectrograph)

Near-infrared adaptive optics-fed integral-field imager and spectrograph

Wavelength range:
0.9–2.5 μm

Field of view:
20 arcsec diameter (imager), 3 arcsecond diameter (spectrometer)

5. GMTNIRS (GMT Near-Infrared Spectrograph)

Near-infrared adaptive optics-fed narrow-field high-resolution echelle spectrograph

Wavelength range:
1.1–5.4 μm

Field of view:
1.2 arcsec (slit length)

What About Webb?

The three ground-based telescopes that are the topic of this double feature — the Giant Magellan Telescope, the Extremely Large Telescope, and the Thirty Meter Telescope — are expected to achieve first light in 2024, 2024, and 2028, respectively. They will no doubt revolutionize astronomy. So what about the James Webb Space Telescope (JWST), due to be launched in 2021? How does Webb compare to the monster scopes of the future?

Ironically, working against the largest space telescope ever built is its small size. With its 6.5-meter segmented primary mirror, Webb will collect only 3% of the starlight that will hit the 39.3-meter primary of the ELT. Also, its science instruments are designed to fit into a limited space.

However, JWST doesn't suffer from the background glow of the atmosphere or other terrestrial sources. It doesn't need adaptive optics to reach its theoretical angular resolution (some 100 milliarcseconds in the near-infrared). It can operate 24/7. And it can reach further into the mid-infrared than ground-based instruments can (see chart below, left). These are all very important advantages.

In the end, according to Rychard Bouwens (Leiden University, The Netherlands), the first large leaps in early-universe science will come with JWST, by determining the prevalence of both luminous and massive galaxies at early times. JWST will also obtain the highest-quality infrared spectra of distant galaxies. Says Bouwens: "I believe JWST will be the dominant player, doing the most significant discoveries."

According to exoplanet researcher Tyler Robinson (Northern Arizona University), "Webb has the potential to characterize habitable-zone worlds around nearby *M* dwarf stars, so it could sniff out signs of life for these exoplanets, using transit spectroscopy. But the true capabilities of JWST [in this field] will only be understood post-launch."

Cosmologist Richard Ellis (University College London) expects that there will be a lot of synergy between the Webb telescope and the ground-based giants, just like there has been between Hubble and Keck, for instance. "Webb has complementary capabilities," he says. "However, it must be remembered that JWST will have a limited lifetime. My guess is that the community will really miss it when its mission is complete."

▲ **WEBB** The full-scale model of the James Webb Space Telescope appears here in 2005, surrounded by team members on a lawn at NASA's Goddard Space Flight Center.

NASA

between elementary particles — may have slightly increased over cosmic history, although measurements so far have been equivocal. These and other issues in the field of fundamental physics cannot be addressed by particle accelerators, which is why theoretical physicists are as keen to use the instruments of the future as astronomers are.

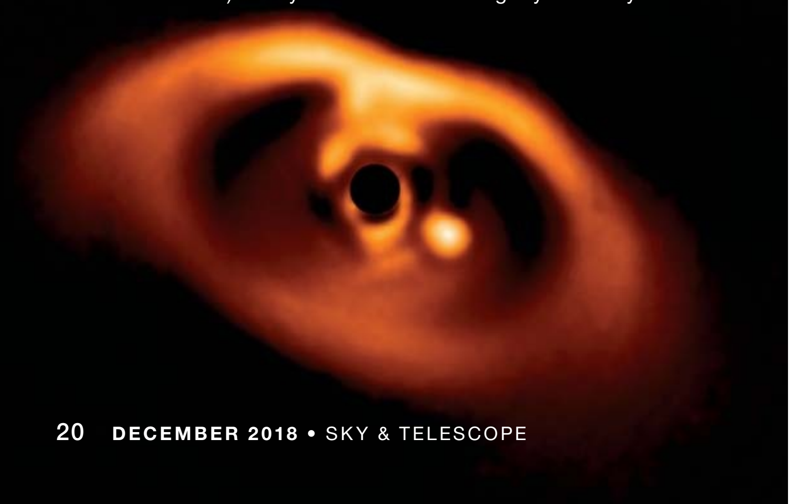
Stars and Planets

Closer to home both in space and in time, astronomers expect to learn much more about the evolution of galaxies and the birth of stars. Here's where the combination of high-resolution imaging and high-precision spectroscopy comes into play. Studying star-forming regions in very early galaxies in detail will reveal how the activity of central black holes influences these processes, and how galaxies acquire their ordered shapes and structures over time. In nearby galaxies, such studies will hopefully shed light on the formation of the most massive stars in the universe (*S&T:* Oct. 2015, p. 24), as well as on the birth of low-mass brown dwarfs and free-floating planetary bodies.

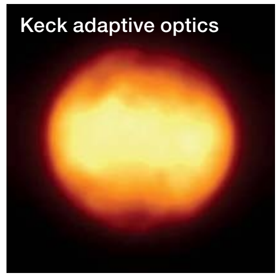
Recent results by the SPHERE instrument at ESO's Very Large Telescope have revealed protoplanetary disks around newborn stars in unbelievable detail; the imaging integral-field spectrometers of the new extremely large telescopes will yield much more detail and provide astronomers with stunning views of the birthplaces of planetary systems. These measurements will be complemented by millimeter and sub-millimeter observations by the 66-dish ALMA observatory in Chile: ALMA remains the instrument of choice to study the chemical composition and the presence of prebiotic molecules in protoplanetary disks, since most spectroscopic signatures of molecules appear at those longer wavelengths.

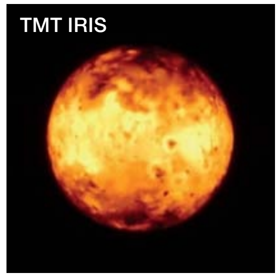
And then there's exoplanet research. While most discoveries of new worlds will be made by dedicated instruments, both in space and on the ground, the monster scopes of the future are particularly suited to study their properties and characteristics. Astronomers know of a handful of potentially habitable Earth-size planets (including Proxima Centauri b, which orbits the nearest star beyond the Sun), and NASA's TESS spacecraft is expected to find dozens more in the solar neighborhood. "So the next key question is, well, what are these worlds actually like?" says exoplanet researcher Tyler Robinson (Northern Arizona University). "Do they have an atmosphere, like Earth? Oceans? Life?"

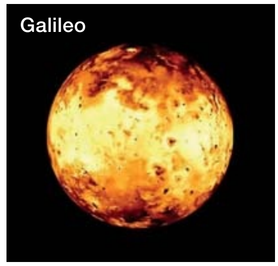
PROTOPLANETARY DISK The glowing dot in this image is a planet forming around the red dwarf star PDS 70. (The central star's light is blocked out.) The system lies about 360 light-years away.



▶ MOON UP CLOSE The Keck telescopes cannot resolve surface details on Jupiter's volcanic moon Io *(top)*. But with the TMT's greater light-gathering power, the telescope's Infrared Imaging Spectrograph should detect small-scale features (*center*, simulated image), not too far off from what appears in a real image from the Galileo spacecraft *(bottom)*.







The European Extremely Large Telescope in particular will play a key role in finding water on Earth-like exoplanets. Because of its huge light-gathering power and the sophisticated coronagraphic (starlight-blocking) capabilities of its METIS instrument, it will be able to directly image such planets around the nearest stars, says Ignas Snellen (Leiden University). Studying an exoplanet's thermal emission and reflected starlight could reveal the spectroscopic fingerprints of water vapor — a feat never before accomplished for an Earth-like exoplanet. For a planet within the right temperature range, the existence of atmospheric water vapor points to liquid surface water.

Finding atmospheric oxygen is going to be much more difficult, says Snellen, because molecular oxygen produces a less conspicuous spectroscopic signature than water. Still, he is hopeful that oxygen could be detected out to distances of a few tens of light-years.

James Kasting (Penn State) is less optimistic. "The ELT may be good for Proxima Centauri b," he says, "but probably not much beyond that. The same is true for the James Webb Space Telescope — it's not supposed to be able to see oxygen." If you also want to detect other gases, like methane or nitrous oxide — promising biomarkers, especially in combination with oxygen — you may need a much larger telescope in space, says Kasting. "Still, I hope to be alive when this happens."

According to Robinson, determining whether or not habitable (water-bearing) worlds and life are common in the universe is the most important next leap in the field of exoplanet science. "It may be that we uncover a huge number of nearby habitable worlds, but also find that virtually none of these show signs of life. That would be humbling — it would say that life is a rare phenomenon. Alternatively, it may be that nearly all of these ocean-bearing worlds show signs of life. That would be extremely exciting. Large telescopes, both

IO: TMT INTERNATIONAL OBSERVATORY; PROTOPLANETARY DISK: ESO / A. MÜLLER ET AL.

in space and on the ground, have the potential to answer these questions."

Solar System Science

While the study of other planetary systems remains a challenge, even for 30-meter-class telescopes, our own solar system presents many opportunities for new discoveries with the next generation of astronomical instruments. Obviously, ground-based telescopes will never be able to compete with spacecraft visiting other worlds, but except for NASA's Juno orbiter at Jupiter, at present there are no planetary explorers observing the giant planets at close range. With their unprecedented resolution — thanks to adaptive optics — the giant telescopes of the future will be able to regularly observe cloud patterns in the atmospheres of Uranus and Neptune, study the seasonal cycles of Saturn's giant moon Titan, and monitor volcanic activity on Jupiter's Io, which will measure hundreds of pixels across in the upcoming cameras.

Because of their huge light-gathering power, the megascopes will also be able to spectroscopically study the surface composition of countless faint asteroids and Kuiper Belt objects and even detect thousands of small outer solar system bodies, out to distances beyond 5 billion kilometers (about 30 astronomical units). Thus, astronomers will gain detailed insight into the dynamical history of our own solar system, which, in turn, will help us understand the formation and evolution of planetary systems in general. Most likely, the GMT, TMT, and ELT will carry out many follow-up observations on small bodies discovered by the future Large Synoptic Survey Telescope, which will scan the heavens twice a week (*S&T:* Sept. 2016, p. 14).

Finally, the giant telescopes will study transient phenomena like novae and supernovae, tidal disruption events created when supermassive black holes tear apart stars in other galaxies, gamma-ray burst afterglows, and, hopefully, the optical and near-infrared counterparts of gravitational-wave detections and the still-mysterious fast radio bursts (*S&T:* July 2016, p. 24). "We're designing the TMT's WFOS instrument in such a way that rapid follow-up observations will be possible," says Bundy.

It's impossible to do full justice to the scientific potential of the monster scopes of the future in just one magazine article, and many exciting research areas haven't been mentioned here. But from this superficial overview, it will become clear that there's no lack of astronomical topics to explore. And these are just the known unknowns: As has always been the case, completely unexpected discoveries may well turn out to await us. As Szentgyorgyi says: "That's what makes it science, as opposed to engineering." Little wonder that the astronomical community can't wait for the new telescopes to achieve first light.

So assuming that all three of the megascopes will indeed be built according to the current specifications, which one will yield the most revolutionary results? That's hard to say. The Giant Magellan Telescope will probably be the first one to be completed, in early 2024 (albeit with only a subset of its seven mirrors, as described in last month's issue), so it may well pick some exciting low-hanging fruit. The Extremely Large Telescope (2024) has the obvious advantage of being the largest by far, and it's also the only one with a true mid-infrared imager/spectrometer (METIS) among its first-light instruments. The Thirty Meter Telescope will come last (2028), but it has the best near-ultraviolet wavelength coverage, and as the only Northern Hemisphere project it will have at least part of the celestial sky to itself. Moreover, the TMT may profit from the experience gained by the GMT and the ELT.

While universities, institutes, and industries all over the world are preparing for the construction of the first-light instruments for the three giant telescopes, scientists and engineers are already thinking about a second generation of cameras and spectrographs. As for the distant future, some astronomers are dreaming about a 15- to 20-meter space-based observatory, covering the ultraviolet, visible, and infrared parts of the electromagnetic spectrum.

▲ **STAR FORMATION** The star-forming region LH 95 in the Large Magellanic Cloud, in visible and infrared light. The bluish nebula is made of hydrogen that's been ionized by the winds and radiation from the region's massive stars.

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA) / ESA HUBBLE COLLABORATION

Surprisingly, almost no one is making a strong case for yet another aperture leap in ground-based astronomy. Does that mean that, with the future extremely large telescopes, we may really have reached the limits of what can be achieved in optical and near-infrared astronomy from Earth's surface? Perhaps. Then again, we thought the same thing half a century ago. It *is* difficult to make predictions, especially about the future.

■ *S&T* Contributing Editor **GOVERT SCHILLING** lives in the Netherlands, where the very first telescopes were built just over four centuries ago. He can't wait to visit the Extremely Large Telescope in Chile after its completion in 2024.

New Year's Eve *Celestial Celebration*

LEAH TISCIONE / S&T

Step outside this New Year's Eve and join the author on an excursion through the stars.

This time of year is nothing without its traditions. One of my favorites is taking a break from the holiday rush to spend time with friends on New Year's Eve and track down all 15 first-magnitude stars visible from mid-northern latitudes. They're all above the horizon at some point between sunset on December 31st, New Year's Eve, and sunrise on January 1st, the morning of New Year's Day. The other six brightest stars in Earth's skies are too far south for most of us clustered here farther north to see without some exciting travel. It's fun to use the boost we get from the long nights around the winter solstice for own little "Naked-Eye Marathon." (Those of you familiar with the Messier Marathon know that the aim is to find as many of the 110 Messier objects in one night as possible.) Let's get to it — bundle up, grab a pre-festivities glass of champagne, maybe even a piece of that giant sandwich, and head outdoors.

The Summer Triangle

The last time most of us contemplated the Summer Triangle, it was likely shining above us after a long, slow, summer sunset. Back in August, the constellations Cygnus and Aquila soared high overhead with Lyra vying for attention, their bright stars lighting up those sweltering nights. Believe it or not, the Summer Triangle's stars are still twinkling in the evening's chilly skies. Let's start our tour with that trio and look westward right after sunset. Just as twilight deepens, we'll see the Swan and Eagle glide toward the horizon as they chase after the Sun.

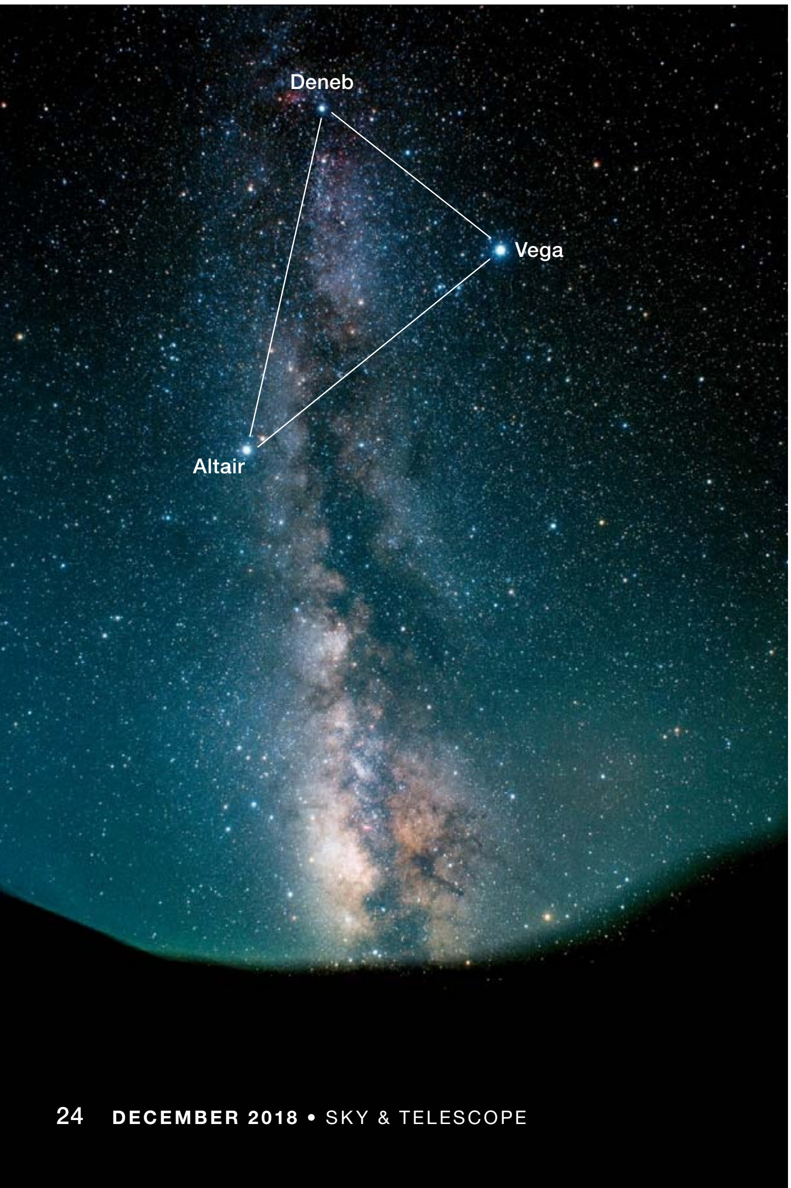
Altair, whose formal name, Alpha (α) Aquilae, indicates that it's the brightest star in the Aquila constellation (there are some exceptions to this convention), and **Vega** (Alpha Lyrae) are among the closest stars to Earth, only about 27 and 25 light-years away, respectively. **Deneb** (Alpha Cygni) anchors the Swan's tail and is, on the other hand, one of the most distant stars we can see with the naked eye. It's an old giant star whose exact distance is a little tough to pin down. Estimates are that its light has been traveling to us for about 2,000 years, with some studies placing it even as distant as 3,000 light-years. Even from that far, it's still very bright, but it remains fainter than the other two — its distance really shows.

The trio is wonderful in summer, but there's something special about seeing these stars in the dusky early evening sky in winter and letting your mind wander back to hot dogs, baseball games, and trips to the beach.

Don't drag your feet on this, but there's no need to rush, either. Altair sets around 7:30 p.m. for viewers at latitudes around 40° north, with Vega and Deneb not too far behind. If you're fortunate enough to live under good, dark skies, away from the worst of the light pollution, you might also be able to make out the Milky Way's glow cutting right through the center of the Triangle.

Dusty Disk

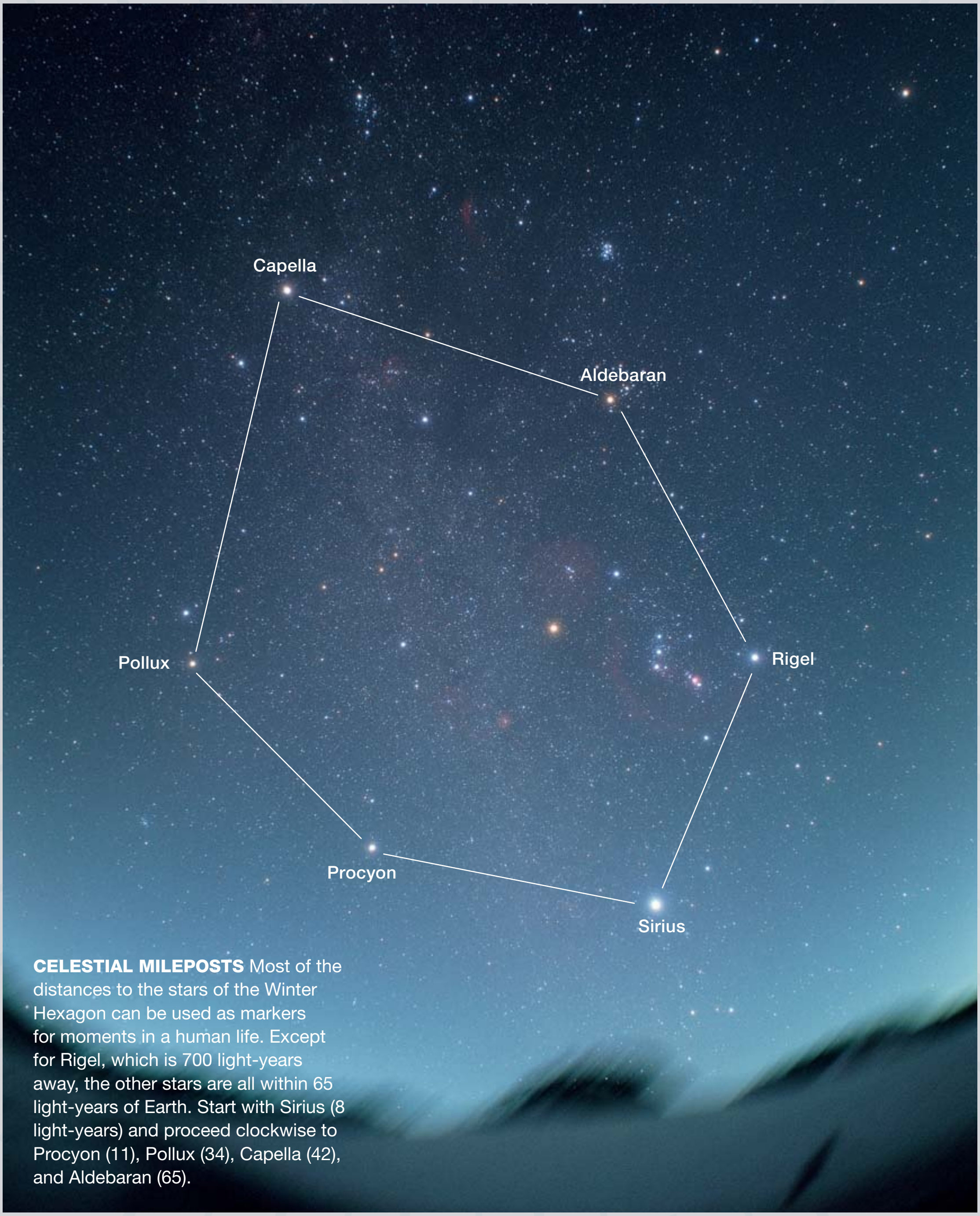
While we're still looking toward the west after locating the first three stars, it's just a quick hop to the fourth. The southernmost first-magnitude star visible in the Northern Hemisphere is **Fomalhaut**, whose name comes from Arabic and means "the mouth of the whale." Piscis Austrinus, the Southern Fish (not to be confused with Pisces, the directionally agnostic fish) is a dim and sparse constellation that can be tough to discern because our view of it puts it low in the southern sky. Fomalhaut, at declination –29°, never rises more than about 20° above the horizon for mid-northern latitudes. Yet as Fred Schaaf mentions in his book *The Brightest Stars*, Fomalhaut is the zenith star for the middle latitudes in the Southern Hemisphere! Traveling south on the celestial sphere, Fomalhaut is the only first-magnitude star between Antares (at declination –26°, more on this star later) and the next one at declination –53°, Canopus in Carina.



◀ **SUMMER TRIANGLE** Surprisingly, the three stars of the Summer Triangle are still visible in the depth of winter. But they're very low on the western horizon right after sunset, so be ready to head outdoors as soon as daylight fades to start your naked-eye marathon. Can you make out the Swan, the Eagle, and the Lyre?

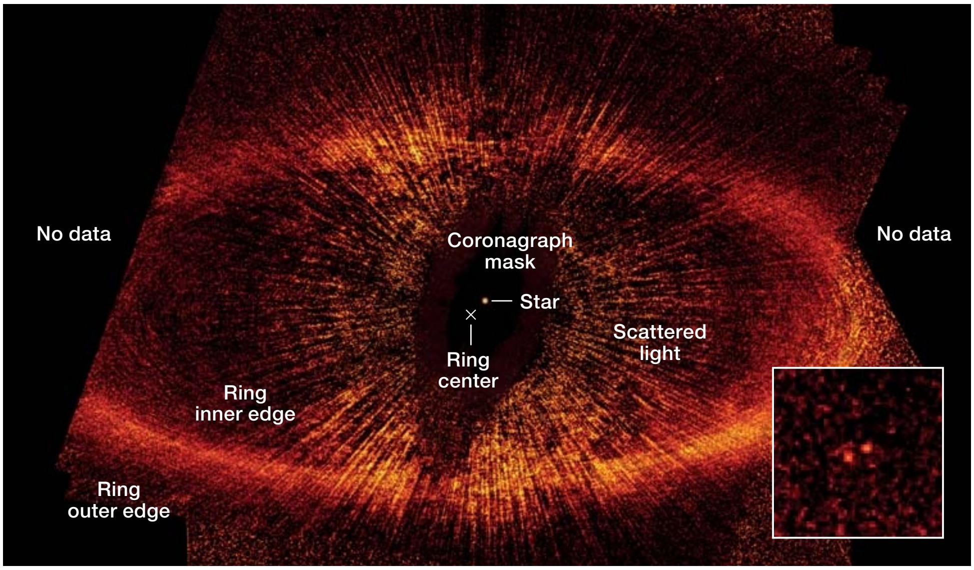
AKIRA FUJII

One by one, the distances to the Hexagon's stars act like a list of milestones throughout a person's life.



CELESTIAL MILEPOSTS Most of the distances to the stars of the Winter Hexagon can be used as markers for moments in a human life. Except for Rigel, which is 700 light-years away, the other stars are all within 65 light-years of Earth. Start with Sirius (8 light-years) and proceed clockwise to Procyon (11), Pollux (34), Capella (42), and Aldebaran (65).

AKIRA FUJII; BACKGROUND LINEWORK: MIAKIEVY / GETTY IMAGES



▲ **DUSTY DISK OF DEBRIS** In 2005, the Hubble Space Telescope directly imaged the disk around Fomalhaut. The coronagraph mask blocks the otherwise blinding light from the star — but some still manages to seep through, seen here as scattered light. The center of the ring is offset from the star, indicating that an unseen body tugs at the disk. The inset shows observations from 2004 and 2006, combined into a single image. The dot is the planet, Fomalhaut b, which has moved in the time separating the two observations. Subsequent observations have confirmed the motion and that the planet is indeed in orbit around the star.

To find Fomalhaut, look at Altair in the last of the glowing twilight, then turn to the south — toward your left. Alpha Piscis Austrini will be the next bright star you come to. Without any other even moderately bright stars nearby to act as signposts, it can be tough to spot, so be patient. When you see it, there's no doubt. It's the only bright star in what's an otherwise humble and quiet part of the sky. It'll be at about the same altitude as Altair and will set at around the same time.

That one point you see in the sky is actually three stars — Fomalhaut A and its two companions, Fomalhaut B and Fomalhaut C. The three stars are all part of the same system, even if they're separated by several degrees. Fomalhaut A is a fairly young star, around 200 million years old, and like Vega approximately 25 light-years away. Its diameter is about twice that of the Sun. When you look at it, bear in mind that you're also looking at an exoplanet embedded in a broad disk of dust, ice, and rock in a long orbit around its parent star. In 2008, the Hubble Space Telescope discovered Dagon (Fomalhaut b), the first exoplanet detected by direct imaging in visible wavelengths, rather than by other indirect methods, such as the transit method. It's incredible to think that we're able to look across that distance and actually see a world orbiting another star (with Hubble, of course!).

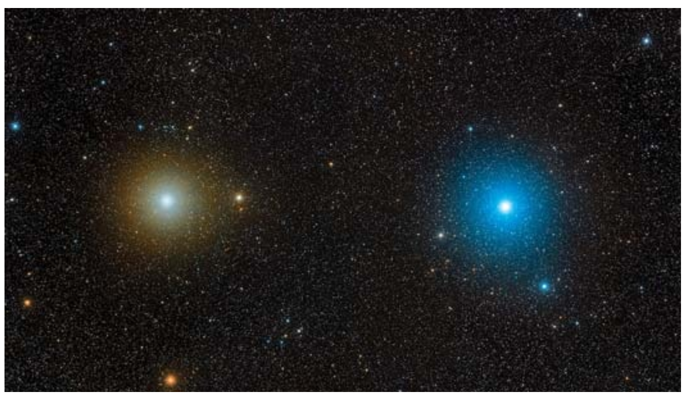
The Winter Hexagon

Now that we have the first four stars on our tour in the bag, let's turn toward the east. For my money, there's no sight in the skies more incredible with the naked eye than the enormous Winter Hexagon. Between the stars that make up the Hexagon and the stars and clusters within and around it, I feel like a kid again every time I see it, even after all these years.

The Winter Hexagon wraps six first-magnitude stars together like a giant present in the sky. **Aldebaran** and **Capella** (Alpha Tauri and Alpha Aurigae, respectively) are already glinting in the dusk after sunset. On long winter evenings, it's fun to pull back the curtains from time to time and watch as the rest of the Hexagon fills the sky as the night goes on. Keep an eye open and watch Orion rise with them, his shield leading the way as he holds off Taurus for another night.

Next we anticipate the appearance of **Rigel**, also known as Beta (β) Orionis, and **Pollux** (Beta Geminorum), followed by **Procyon** (Alpha Canis Minoris). Alpha Canis *Majoris*, famously known as **Sirius**, is the last of the Hexagon's stars to rise. It's unmistakably the brightest star in the night, more than twice as bright as the second-brightest, the southern star Canopus. Sirius easily outshines everything else in the nighttime sky except the Moon, Venus, and Jupiter. The Sirius we see is actually a pair: a white star about twice the size of the Sun (Sirius A) and a dim companion (Sirius B), sometimes called "The Pup," in reference to Sirius's moniker, the Dog Star. Sirius B is a white dwarf that has about the same mass as the Sun squeezed into a sphere approximately the size of the Earth.

Every year, I like to grab a friend or my kids at this moment and step outside to have a look just before the horns blow.



▲ **TWINS IN SPACE** Castor and Pollux are the heads of the twins in the Gemini constellation. Pollux, one of our first-magnitude stars, is a red giant and has a gas giant planet orbiting it. Castor, not far behind at magnitude 1.94, is a bluish-white main sequence star and is part of a multiple-star system.

FOMALHAUT: NASA / ESA / P. KALAS / J. GRAHAM / M. CLAMPIN; CASTOR AND POLLUX: ROGELIO BERNAL ANDREO

Where do our bright stars sit in the Hertzsprung-Russell diagram?

The Hertzsprung-Russell (HR) diagram is a useful tool that plots stars' luminosities against spectral classes. Spectral class indicates the relative abundance of the different elements in stars and correlates with temperature, so *O* and *B* stars are hotter than *K* and *M* stars. Most stars are on the *main sequence*, which runs diagonally from upper left to lower right indicating that hotter stars are more luminous while cooler stars are less luminous. The main sequence is where stars spend the majority of their time, fusing hydrogen in their cores. When their fuel supply starts to deplete, stars evolve off the main sequence and enter the *giant* and then, if they're massive enough, *supergiant* branches. Giant stars' final gasps are manifested as planetary nebulae surrounding a *white dwarf* remnant. Supergiants tend to be more self-destructive and explode as supernovae, leaving behind neutron stars or black holes.

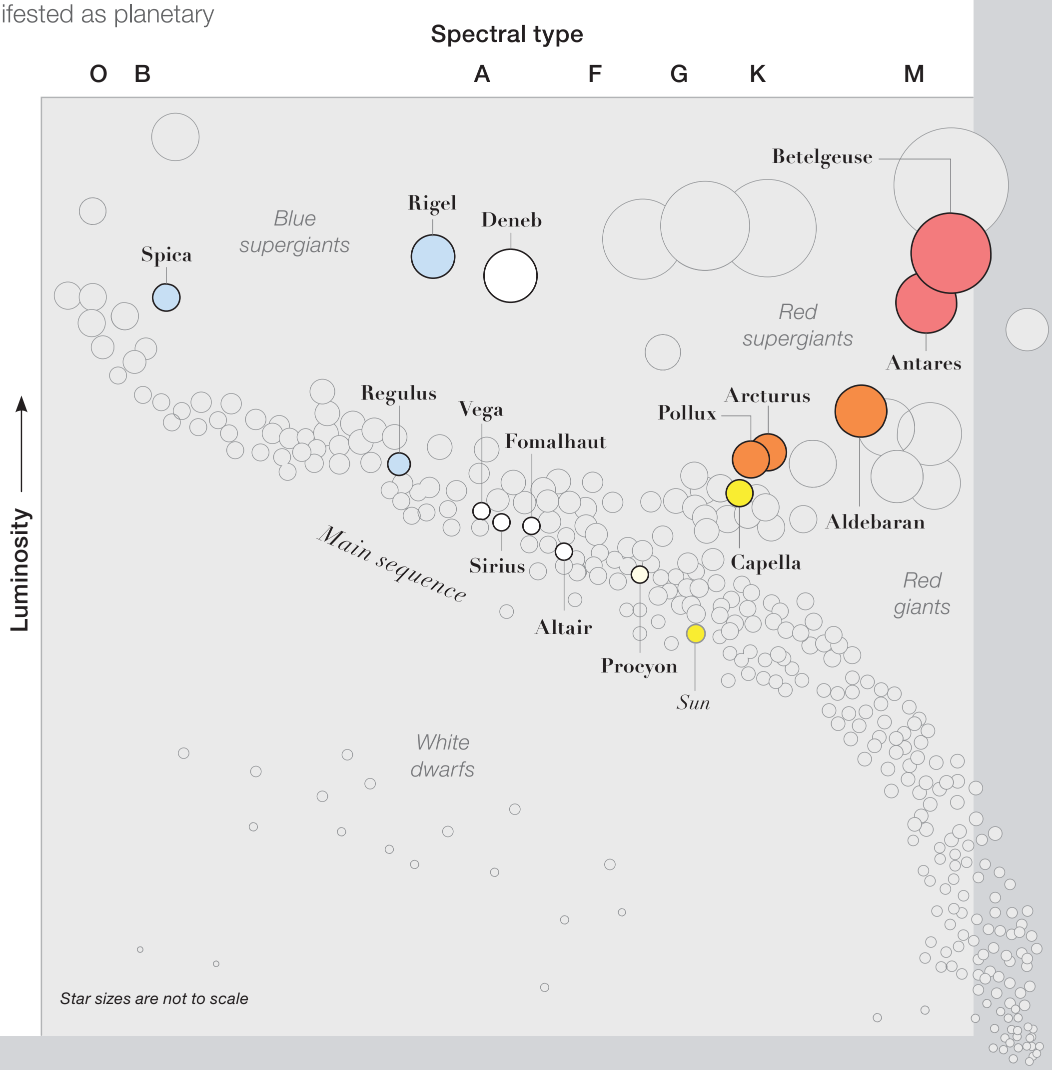
Astronomers use shorthand to indicate where on the HR diagram a particular star might be. Take the Sun, for example, classified as a *G2V* star. You can immediately tell that it is a yellow star of moderate temperature, with a specific proportion of elements (spectral classes have decimal subdivisions that further refine the abundances), and is on the main sequence. Take a look at Deneb, which is an *A2Ia* star (luminosity classes are also further subdivided): The "code" tells you it's a white supergiant, and you'll find it in the upper left of the supergiant branch in the HR diagram.

Spectral Classes

Spectral Class	Characteristics
O	Hottest; blue
B	Blue-white
A	White
F	Yellow-White
G	Yellow
K	Orange
M	Coolest; red

Luminosity Classes

Luminosity Class	Type
I	Supergiant
II	Bright giant
III	Giant
IV	Subgiant
V	Dwarf

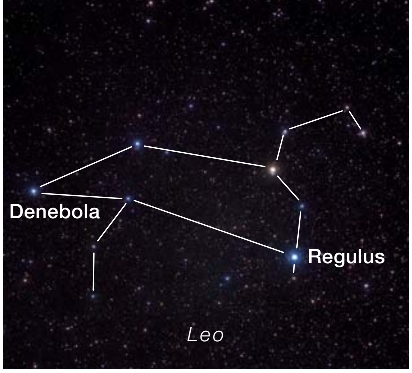


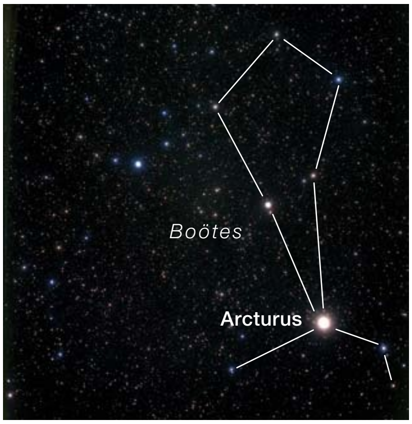
TERRI DUBÉ / *S&T*

Counterclockwise around the Hexagon are golden-yellow Capella, yellow-orange Pollux, white Procyon, icy blue-white Sirius and Rigel, and orange Aldebaran. Even though it's not a first-magnitude star, I like to include Castor (Alpha Geminorum), Pollux's twin brother, at this point, since it rounds the hexagon out into a circle and gives a soothing rhythm to the stars' names. Try saying it and you'll see.

Hiding just beyond the names and their bright lights is a wonderful notion that seems fitting as we look back on the last year. With the exception of Rigel, which is about 700 light-years away, all of the stars in the Hexagon are fairly close by. Sirius is only about 8 light-years distant, so you if you have a third-grader handy you can tell her that the light she's seeing from Sirius left on its long voyage to her eye right around the time she was born.

One by one, the distances to the Hexagon's stars act like a list of milestones throughout a person's life. Procyon is 11 light-years away — a kid starting middle school. Pollux is around 34 light-years, maybe marking the time when people are starting families of their own. Capella, high above, in Auriga, is about 42 light-years distant; that's us inching toward midlife. The light leaving Aldebaran, the farthest of the six (apart from Rigel), takes 65 years to arrive at Earth, the lifetime of a retiree.





◀ **LEO THE LION AND BOÖTES THE HERDSMAN** Regulus, the twinkling front paw of the Lion, and Arcturus, the lucida in Boötes, form the Spring Triangle along with Spica in Virgo. Some sources prefer Denebola over Regulus to complete the triangle. Which triangle do you see better?

While we're here, don't forget bright orange **Betelgeuse** (Alpha Orionis), right in the middle of the Hexagon. Thanks to Betelgeuse and Rigel, Orion is the only constellation in the northern sky with two first-magnitude stars.

Now we're up to 11 stars and it's not even midnight!

If it's not too cold, and you have a few extra minutes, stay outside for a little while, let your eyes adjust to the dark, and take a look at some other objects. Aldebaran appears to be in a V-shaped group of stars — that's the Hyades, the closest star cluster to Earth, about 150 light-years away. But Aldebaran isn't part of the cluster. Instead, it's in front of it from our perspective, only 65 light-years distant. West of the Hexagon, look for the Pleiades cluster (Messier 45) and count how many of the Seven Sisters you can see.

The Bright Stars of New Year's Eve

Object	Constellation	Meaning	Mag(v)	Spectral Type	RA	Dec.
Altair	Aquila	Eagle	0.77	*A*7V	$19^h 50.8^m$	+08° 52′
Vega	Lyra	Lyre	0.03	*A*0V	$18^h 36.9^m$	+38° 47′
Deneb	Cygnus	Swan	1.25	*A*2Ia	$20^h 41.4^m$	+45° 17′
Fomalhaut	Piscis Austrinus	Southern Fish	1.16	*A*3V	$22^h 57.7^m$	–29° 37′
Aldebaran	Taurus	Bull	0.85	*K*5III	$04^h 35.9^m$	+16° 31′
Capella	Auriga	Charioteer	0.08	*G*5IIIe+*G*0III	$05^h 16.7^m$	+46° 00′
Rigel	Orion	Orion, the Hunter	0.12	*B*8Ia	$05^h 14.5^m$	–08° 12′
Pollux	Gemini	Twins	1.15	*K*0III	$07^h 45.3^m$	+28° 02′
Procyon	Canis Minor	Smaller Dog	0.34	*F*5IV	$07^h 39.3^m$	+05° 13′
Sirius	Canis Major	Larger Dog	–1.47	*A*1V	$06^h 45.1^m$	–16° 43′
Betelgeuse	Orion	Orion, the Hunter	0.50	*M*2Ib	$05^h 55.2^m$	+07° 24′
Regulus	Leo	Lion	1.35	*B*7V	$10^h 08.4^m$	+11° 58′
Arcturus	Boötes	Herdsman	–0.04	*K*2III	$14^h 15.7^m$	+19° 11′
Spica	Virgo	Virgin	0.98	*B*1V	$13^h 25.2^m$	–11° 09′
Antares	Scorpio	Scorpion	0.96	*M*1.5Iab	$16^h 29.4^m$	–26° 26′

Right ascension and declination are for equinox 2000.0.

AKIRA FUJII (2)

Do you have binoculars with you? Now's a good time to take them out. The Hyades and Pleiades are beautiful with the naked eye, but if you have a pair of binoculars, they're spectacular. It's always astonishing how many more stars you see through binos. As cliché as it might be, the Pleiades are my favorite thing to look at in the sky.

While you're still out, don't forget to look for the cloudy Orion Nebula (Messier 42) in the middle of Orion's sword. With my binoculars, I love to pick out the far-away Trapezium Cluster in the middle of the Orion Nebula's dust, even if I might not make out the individual stars.

But now let's get back to our marathon.

The Spring Triangle

Happy New Year! As we greet the first few minutes of 2019, you can run back in from the cold and tell your friends that you've already found 11 of the 15 northern first-magnitude stars! The last four will take some planning. Even though it's getting late, we'll get the New Year off on the right foot.

Right around the same time that Sirius culminates (reaching its highest and southernmost point in the sky), the confetti falls at midnight on New Year's Eve, and the three stars of the Spring Triangle gradually appear in the east. **Regulus** (Alpha Leonis) is first. I always think of the little king as something of the groundhog of stars. When I see Leo staring back at me on a mid-February evening, I know warmer weather is just around the corner. Tonight spring is still a long way off, though. Here in the first few days of winter, Regulus rises around 8:30 p.m., but it might not be high enough above the rooftops and trees to see easily until the middle of the night.

Regulus is the dimmest of all the first-magnitude stars, so it might not jump out at you at first. It's helpful to look for it at the bottom of the backward-question-mark-shaped "sickle" asterism at the lion's front end.

One of my favorite stars is **Arcturus** (Alpha Boötis), which joins the fun just after midnight. It's the fourth-brightest star in the entire sky, and the second brightest visible in the north. It's a red giant about 37 light-years away that — like Aldebaran and Pollux — has aged and left the main sequence (see page 27). About 6 billion years from now, our Sun will also evolve into a red giant when it, too, has used up all of the hydrogen fuel in its core and moved to fusing the shell of hydrogen around the core. In a way, looking at Arcturus is like looking at our own future.

Finally, at around 1:30 a.m. on New Year's morning, **Spica** (Alpha Virginis) rises, and we've completed the Spring Triangle. Spica is another of our bright stars that's part of a binary system. Both components are very hot and bright. The larger of the two has a luminosity more than 13,000 times that of our Sun, its diameter is nearly 8 times wider, and its mass about 11 times — this star may one day go supernova (but only in the distant future). The second component is none too shabby, with corresponding numbers of 1,700 times solar luminosity, around 4 solar diameters, and almost 7 solar masses.

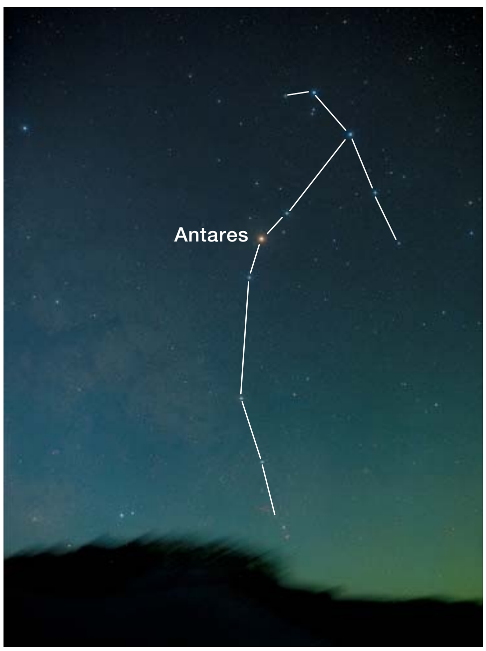
Heart of the Scorpion

The last star on our tour is the bright red supergiant **Antares** (Alpha Scorpii). The heart of the Scorpion takes some real commitment, because it doesn't rise until just before dawn on New Year's morning.

Like Fomalhaut, Antares never gets higher than about 20° off the horizon. Most of us are used to seeing it in July and August — bright, red, and fiery — so it might be a little confusing and unsettling to see the Scorpion sneaking by on a cold morning. It's always fun to see stars out of season, though, isn't it? You'll need to time it so that you see Antares before the Sun rises and washes it away. Maybe try to see it on the morning of December 31st as well. That way, you get two chances. Plus, you'll probably have the morning all to yourself, before the noise of the day starts.

Either morning, take a minute and look around a bit. This year, we have an extra reason to be up early — or still awake! Just to Antares's left will be the planets Mercury, Jupiter, and Venus in a spectacular line that runs from right above the eastern horizon into Libra, with the Moon as a cap at the top. Waning crescent Moons like these are particularly wonderful. They're subtle and disorienting, backward from the waxing crescents most of us are used to seeing in the evenings.

I don't always catch them all, but the holidays wouldn't be the same without at least trying to see these 15 stars. Whether you're new to the skies or have been watching for decades, it's a great way to spend the New Year with some old friends. I hope you'll give it a try.



AKIRA FUJII

▶ **NEW YEAR'S MORNING** See if you can catch smoldering Antares as it rises just before the Sun. The heart of the Scorpion is a red supergiant expected to eventually go supernova. But that won't be for a while. This morning, enjoy wrapping up your bright-star jaunt with this glowing ember, and try to catch the planets rising in the east, too. As you drift off to sleep after this long night, take the memory of the sparkling stars with you.

■ **SCOTT LEVINE** is a writer who has loved space and giant sandwiches since Voyager flew past Saturn when he was a kid, and he hasn't stopped talking about any of them. He'd love to hear from you at **astroscott@yahoo.com.**

TYCHO REMNANT In 1572 Tycho Brahe unknowingly watched a white dwarf obliterate itself in a Type Ia supernova. New research shows that the partners left behind in such detonations litter — and in some cases flee from — our galaxy.

The Fastest Stars

Exploding white dwarfs can hurl their companions away at record speed, dooming them to roam intergalactic space for all eternity.

White dwarfs are extreme — so dense that a single spoonful weighs tons. These tiny dying suns are the prime movers behind a newfound phenomenon that features another extreme: the fastest stars ever seen fleeing the Milky Way.

The key to the drama is the white dwarf's minuscule size, only about 1% the diameter of the Sun, or about as small as Earth. Another star can therefore orbit just a few thousand miles from the white dwarf's center, whizzing around it much faster than a distant companion would, for the same reason that Mercury moves much faster than Pluto. In such a close orbit, the white dwarf can steal gas from its mate and gain enough mass to annihilate itself in a Type Ia supernova. Then the companion dashes away as fast as it had once been racing around its now vanished and vanquished partner.

Recently, astronomers have started seeing small and swift stars that look just like these predicted runaways. "This is very exciting," says Stephan Geier (University of Potsdam, Germany). "We are at the very beginning here. There are lots of open questions."

The few known members of this new stellar class share certain characteristics. All are fainter than Pluto. All are hotter but smaller than the Sun. And all are on a one-way trip out of the galaxy, never to return.

Evicted from the Galaxy

Outweighing the Sun a trillion times over, the Milky Way Galaxy is so massive that escaping its gravitational grasp requires enormous speed. The Earth's escape velocity is 11.2 kilometers per second (25,100 mph), which means a rocket must attain that speed to reach outer space. But the galaxy's escape velocity is some 50 times greater, between 500 and 600 km/s. That's more than twice the Sun's speed around the galactic center.

X-RAY: NASA / CXC / SAO, INFRARED: NASA / JPL-CALTECH; OPTICAL: MPIA / CALAR ALTO, O. KRAUSE ET AL.

Now the wounded white dwarf sails through space on its own, minus the partner that set off the fireworks.

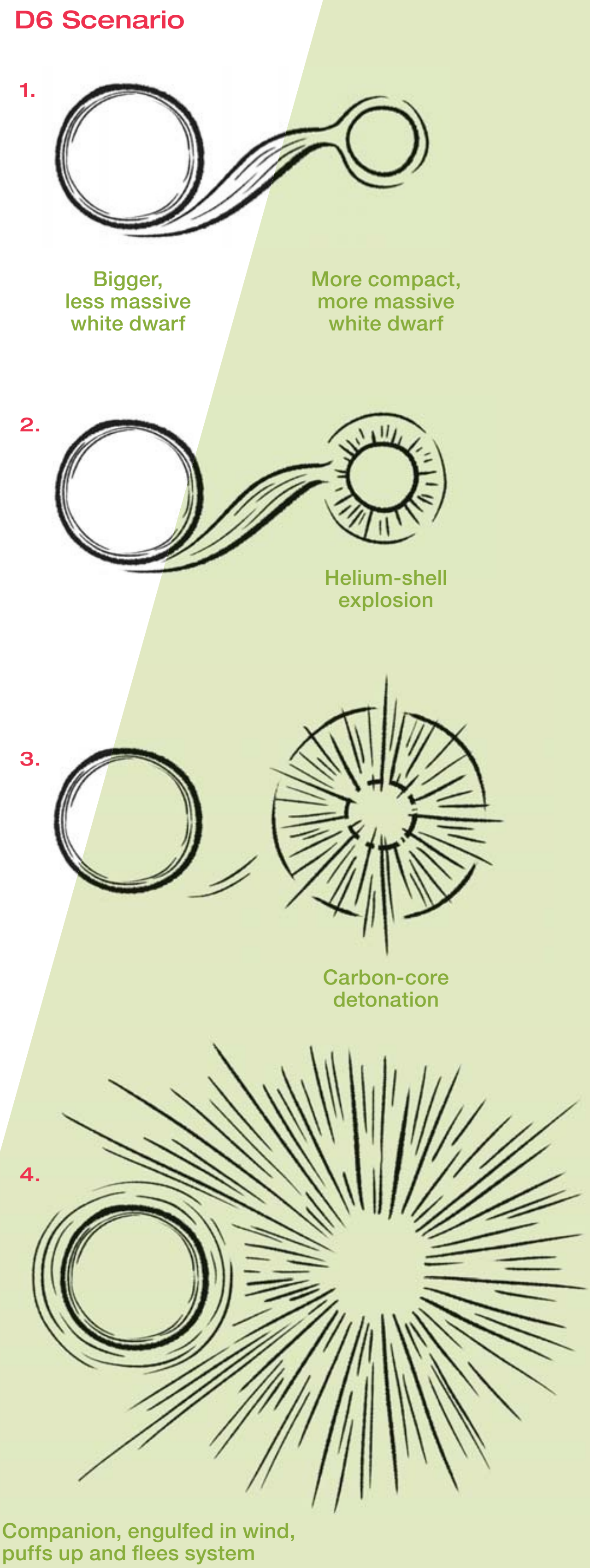
In 2005 Warren Brown (Smithsonian Astrophysical Observatory) found the first "hypervelocity" star — that is, the first gravitationally unbound star ever seen: a luminous blue star that the big black hole at the galaxy's center had shot into the halo (*S&T:* May 2005, p. 20). The only stars moving faster are those whirling close around the black hole or else stars in close binaries whirling around each other.

That same year saw the discovery of another hypervelocity star, one that now seems to be the first of an elite new fleet. Residing far away in Ursa Major, the star was number 708 in a catalog of faint blue objects that Peter Usher (Penn State) and colleagues had compiled two decades earlier. Although the star's name, US 708, sounds like an American highway, it was astronomers in Germany who uncovered the star's extraordinary nature. The Doppler shift they measured revealed that the star will escape the Milky Way.

Unlike most hypervelocity stars, which are hot, blue, and intrinsically bright, US 708 is hot, blue, and intrinsically

ESCAPING the Galaxy

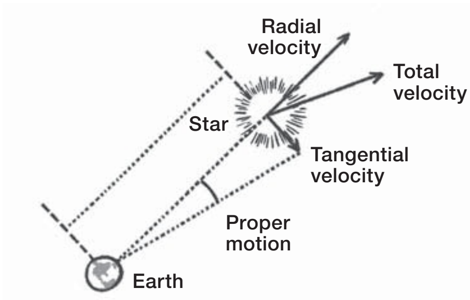
modest. It is an O-type subdwarf, a star larger than a white dwarf but smaller than a main-sequence star of the same temperature. Unlike the Sun, it has no detectable hydrogen but consists mainly of helium. The astronomers attributed the star's high speed to a brush with the Milky Way's central black hole, the source of most other hypervelocity stars. Recently, though, after theorists proposed that the star might instead be a supernova runaway, Geier and his colleagues took a closer look.



▶ **DOUBLE TROUBLE** White dwarf–white dwarf binary systems can result in a detonation that flings the less massive star away. In the *dynamically driven double degenerate double detonation* scenario, the less massive star donates mass to the more massive one (frame 1), triggering a helium-shell explosion (frame 2), and ultimately a carbon-core detonation (frame 3). The surviving companion, engulfed in hot supernova debris, puffs up and ultimately flees the scene and, in some cases, the entire galaxy (frame 4).

LEAH TISCIONE / S&T

THE GAIA MISSION Launched on December 19, 2013, the Gaia spacecraft is measuring distances and velocities of more than a billion stars in the Milky Way. The spacecraft has helped astronomers discover new hypervelocity stars as well as better establish the properties of known ones.



▲ **3D VELOCITY** Although measuring the Doppler shift of spectral lines provides astronomers with an object's radial velocity, it's really just a lower limit: Observers don't know its total 3D velocity until they also measure its proper motion and distance.

"We found that the star was much faster than we thought before," he says. The extreme Doppler shift had clocked only the star's speed *along* our line of sight. But Geier's team examined the star's position on old photographic plates to measure its proper motion, the apparent movement *across* our line of sight. Newly released data from the Gaia mission give an updated speed: The star darts through space at about 1,060 km/s. Furthermore, the trajectory shows that the star has never been anywhere near the galactic center. So the Milky Way's big black hole didn't eject the star.

The astronomers also discovered that US 708 spins fast. Geier thinks the rapid spin arose because the star had been tidally locked — it had circled a white dwarf every 10 minutes and spun that fast itself, for the same reason that the Moon spins as fast as it revolves. The star had once been a red giant, but the white dwarf tore off the giant's hydrogen atmosphere, leaving only the compact helium core we see today. When the white dwarf exploded, US 708 flew away.

And Then There Were Two

Meanwhile, other astronomers were tracking a strange star in Ursa Minor named LP 40-365. "This one stood out as being extremely fast," says Stéphane Vennes, then at the Academy of Sciences of the Czech Republic. "In fact, a quick back-of-the-envelope calculation showed that it was actually not even bound to the Milky Way." Yet this star had also never ventured near the galaxy's central black hole.

Unlike US 708, which an exploding white dwarf had flung away, LP 40-365 seems to be an actual white dwarf that partially blew up. "It survived a supernova explosion," says Vennes. His team found chemical elements on the star that its own explosion had created. As with a normal Type Ia explosion, the white dwarf's partner dumped gas onto it, but the resulting explosion fizzled, sparking a not-so-super supernova, one that failed to completely destroy the white dwarf. Now the wounded white dwarf sails through space on its own, minus the partner that set off the fireworks.

Another team, led by Roberto Raddi (Friedrich-Alexander University, Germany), strengthened this conclusion by discovering that the star had manganese, an element that originates chiefly in Type Ia supernovae. Moreover, manganese forms most readily when the exploding white dwarf's partner is not a white dwarf itself.

The energy from the explosion puffed up the white dwarf, making it larger than normal. In April, when the Gaia team published its newest data release, Raddi's team found that the star is about 2,060 light-years from Earth and moving at 850 km/s, well above the Milky Way's escape velocity. The distance yields the star's luminosity and diameter, both of which are about a fifth of the Sun's. This means the star is 15 times larger than a typical white dwarf.

Life in the Fast Lane

Within hours of receiving the new Gaia data, Ken Shen (University of California, Berkeley) and colleagues spotted three more high-speed stars. All three are puffed-up white dwarfs with strange chemical abundances: Unlike most white dwarfs, their spectra show no hydrogen but instead lots of carbon, oxygen, magnesium, and calcium.

"This is a super interesting discovery," says Geier, who was not part of the study. "They are not only very weird; they are also very similar to each other."

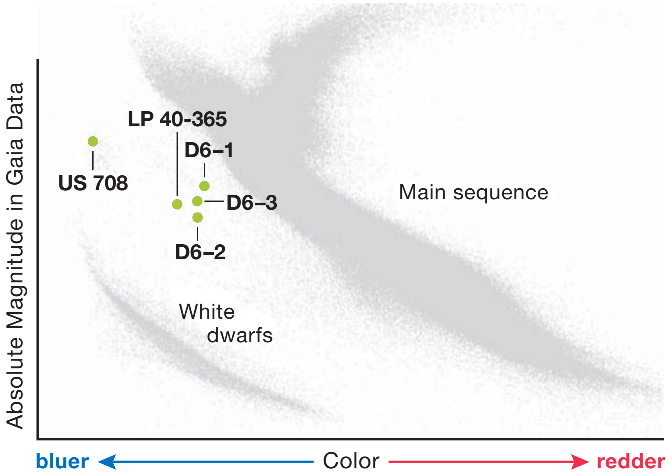
These stars are hurtling through space at incredible speeds. The most extreme are D6-1 in Apus and D6-3 in Draco. "These stars are probably the two fastest unbound

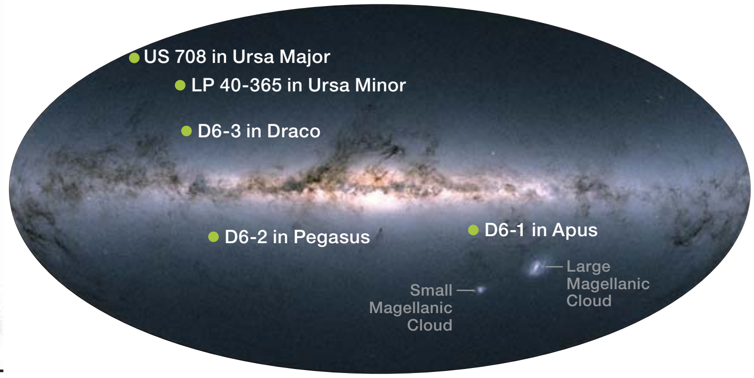
Swift and Small: The New Hypervelocity Stars

Designation	Constellation	Distance (light-years)	Temperature (kelvin)	Apparent Magnitude*	Absolute Magnitude*	Velocity** (km/s)	(mph)
US 708	Ursa Major	28,000	47,000	18.7	+4.0	1,060	2.4 million
LP 40-365	Ursa Minor	2,060	9000	15.6	+6.5	850	1.9 million
D6-1	Apus	6,900	8000	17.4	+5.5	2,300	5.1 million
D6-2	Pegasus	3,100	8000	17.0	+6.9	1,300	2.9 million
D6-3	Draco	7,600	8000	18.3	+6.3	2,400	5.4 million

*As measured by Gaia
**Relative to the Milky Way's rest frame. The Sun's velocity is about 250 km/s or 560,000 mph.

LEAH TISCIONE / S&T





▲ *Left:* The Hertzsprung-Russell diagram, as measured here by the Gaia mission, shows stars' luminosities versus their color. Most stars fall along the main sequence, while white dwarfs bunch together at lower luminosities. The five hypervelocity stars are larger and brighter than typical white dwarfs but smaller and dimmer than main-sequence stars of the same temperature. *Right:* This all-sky diagram shows where the five runaway stars are located; the Milky Way's plane runs horizontally across the middle, with its core at center.

stars in the galaxy," Shen says. They travel at roughly 2,300 and 2,400 km/s, respectively — more than 5 million mph, or 0.8% the speed of light. At that rate you could zip from Earth to Pluto in a month.

The three high-speed stars all arose in the same way, he thinks, in systems with two white dwarfs. The less massive white dwarf dumped gas onto the more massive one, where helium exploded on its surface. That explosion then triggered a far more lethal one: It ignited the massive white dwarf's carbon core, blowing up that star and freeing the other, which dashed away at high speed. Quite a way to get out of an unhappy marriage.

The names of the three newly discovered stars reflect their origin. White dwarfs are degenerate stars, made of matter so dense it behaves like a metal rather than a gas. The more massive white dwarf in the binaries suffered two explosions, and the first explosion occurred because the transfer of gas from star to star had been violent. So this picture bears the alliterative term "dynamically driven double degenerate double detonation," explaining the "D6" in the stars' names.

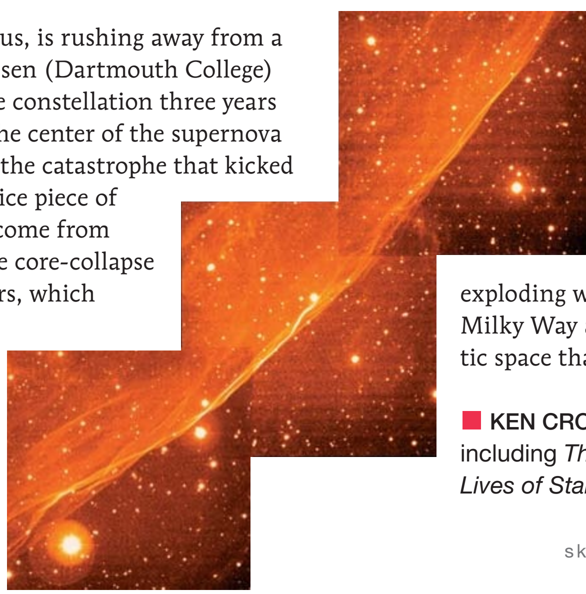
One of the stars, D6-2 in Pegasus, is rushing away from a supernova remnant that Robert Fesen (Dartmouth College) and colleagues spotted in the same constellation three years ago. The star would have been at the center of the supernova remnant 90,000 years ago, dating the catastrophe that kicked the star away. "That was a really nice piece of evidence that these stars actually come from supernovae," Shen says. Plus, while core-collapse supernovae spring from young stars, which inhabit the Milky Way's disk, this supernova remnant is more than 1,000 light-years below the galactic plane, pointing to an origin from an older star, an exploding white dwarf.

"We got very lucky," Shen says, "that these three stars turned out to be much brighter than we expected. If they hadn't been so bright, I think we would have seen none." The stars are so luminous because the supernova explosions that freed them also made them expand, causing them to be larger than ordinary white dwarfs. Over time, he says, the bloated stars will shrink and heat up, perhaps coming to resemble US 708, the first and the hottest of the new breed of hypervelocity stars. Then they will start to cool and fade as white dwarfs normally do.

Haste Makes Waste

The exquisite new Gaia data must harbor other hypervelocity stars that exploding white dwarfs have flung away. But, Geier warns, "we — the people looking for extreme objects — have to be very careful." With 1.7 billion stars in the catalog, the Gaia data must have errors. "Nothing is perfect," he explains. "There must be outliers in there. Those outliers can appear to have very extreme properties which are just not real."

With that caution in mind, astronomers will continue their quest for the galaxy's swiftest stars. A larger sample of such stars should provide more insight into how exploding white dwarfs catapult stars out of the Milky Way and into the vast expanse of intergalactic space that will soon engulf them.



▶ **SMOKING GUN** This hydrogen-alpha image captures part of the supernova remnant that the hypervelocity star D6-2 is fleeing.

■ **KEN CROSWELL** is the author of eight books, including *The Alchemy of the Heavens* and *The Lives of Stars*.

HERTZSPRUNG-RUSSELL DIAGRAM: K. SHEN ET AL. / *ASTROPHYSICAL JOURNAL* 2018: ALL-SKY DIAGRAM: LEAH TISCIONE / *S&T*, BACKGROUND: ESA / GAIA / DPAC, ACKNOWLEDGEMENT: UNIVERSITY OF LISBON; SUPERNOVA REMNANT: ROBERT FESEN (DARTMOUTH COLLEGE)

Another ship joins the Mars armada when the Insight lander touches down in late November. What further science can a stationary lander add? After all, the Red Planet's skies and surface are already plied by eight spacecraft. Curiosity roves up the slopes of towering "Mount Sharp," and Opportunity might yet recover from its deep hibernation during this year's global dust storm (*S&T:* Sept. 2018, p. 11). NASA also has Odyssey, Mars Reconnaissance Orbiter, and MAVEN in orbit. ESA operates Mars Express and ExoMars Trace Gas Orbiter, while India's space agency flies its Mars Orbiter Mission. China, Japan, and the United Arab Emirates all have Mars spacecraft under construction.

The answer lies in the mission's full name: Interior Exploration Using Seismic Investigations, Geodesy and Heat Transport (though even its scientists often don't spell this out in their papers). "Insight," the much simpler backronym it's known by, is designed specifically to understand the structure of Mars's deep interior.

If successful, this spacecraft will reveal the thicknesses and characteristics of Mars's interior layers, determine how fast the planet is losing its heat to cold space, and reveal how much its rocks shake with marsquakes. And the modest-size, 360-kg (790-pound) craft will do all this with just three experiments:

The Seismic Experiment for Interior Structure (SEIS) is a seismometer that can record ground motion due to marsquakes, asteroid impacts, wind, and even the teeny tidal tug of Phobos. NASA scientists have tried to do Martian seismology before, using the Viking landers in the mid-1970s. But Viking 1's seismometer failed to free itself from a protective "cage," and Viking 2's detected only wind — because the instrument sat atop the lander, unable to record Mars's

▼ **HEART OF MARS** NASA's Insight mission will probe the interior of Mars to determine the size, state, and composition of its core, as well as the structure of its crust and mantle — questions that geophysicists have dreamed of answering since such a mission was conceived in the late 1980s.

Mars: The INSIDE Story

With the arrival of NASA's Insight lander, geophysicists hope to learn what goes on deep in the Red Planet's interior.

slight ground motions. In contrast, SEIS will be directly on the surface, covered by a protective lid to shield it from wind and temperature changes.

The Heat Flow and Physical Properties Probe (HP^3) will penetrate deeply into the ground to escape the wide temperature swings on the surface and to measure how fast heat is escaping from the Martian interior, as well as how the subsurface temperature responds to changing seasons.

And in the Rotation and Interior Structure Experiment (RISE), radio dishes on Earth will use their connection with Insight's transmitter to measure minute wobbles in Mars's motion that are consequences of the layering deep within the planet.

▲ **NOISE-CANCELING DOME** This tent-like shield will ensure that Insight's SEIS instrument (seen at bottom) is protected from seismic "noise" generated by Martian winds and wide temperature fluctuations.

A fourth instrument package, the Auxiliary Payload Sensor Subsystem (APSS), is technically a subcomponent of SEIS. It's a suite of meteorology sensors and a magnetometer intended to help remove weather effects from the SEIS measurements. But there'll be scientific value in the APSS observations, too — for example, by comparing the weather at Insight's landing site with that measured by Curiosity (using nearly identical instruments) in the deep hole of Gale crater just 600 kilometers away.

NASA scientists typically place their landers in geologically interesting settings. But not so with Insight. Flat terrain is the simplest possible shape to simulate in computational models of heat flow and earthquake waves. So Insight's team deliberately picked a landing site that's as dull as possible, flat and bland in every direction. It also had to be near the equator, to maximize the sunlight falling on the lander's solar-cell arrays. The winning candidate is a spot in western Elysium Planitia at 4.5° north latitude and 135.9° east longitude.

Readying for Work

Assuming that Insight lands without incident on November 26th, its first task will be reconnaissance. For three weeks, the camera on its arm (a spare from the Curiosity mission, refurbished with a color detector) will methodically survey the landing site, while the weather package begins routine monitoring. Insight has one other camera, likewise repurposed from Curiosity and refurbished to capture color, to provide a fish-eye view of the workspace within reach of Insight's robotic arm.

With the help of those early images, the science and engineering teams will choose where to place the seismometer and heat probe. Then they'll use the robotic arm to lift and place SEIS, its cover, and HP^3 on the ground. The arm has a grapple at the end of a short cable that will snare specially designed hooks on these three packages. All of these activities must be slow and deliberate — from landing to complete instrument deployment should take about 10 weeks.

Being set on the ground is only step one for deploying HP^3. Next, its "mole" has to burrow into Mars. The mole is a cylinder 27 millimeters (about an inch) in diameter and 40 centimeters (16 inches) long, with a pointed tip and a tether that connects it to the instrument's main package on the surface. Inside are two spring-loaded weights that can wind up and hammer in a two-stroke cycle to bang the mole into the ground — roughly 1 mm at a time.

All this hammering (an estimated 5,000 to 20,000 hits) will be easily detectable by SEIS. It will not only sense the taps transmitted directly through the soil but perhaps also the echoes that bounce off geologic layers or large rocks within the soil beneath the lander.

After every 50 cm (20 inches) that the mole penetrates, it will stop to "rest." To get accurate data on how heat flows within the Martian soil, mission scientists must wait about 4 days for the heat generated by drilling to dissipate. Then they'll use tiny heaters inside the mole to inject a known amount of heat into the soil, and the temperature sensors on its tether will record how that heat pulse propagates upward.

The mole will repeat this burrow-rest-heat cycle until either it has penetrated 5 meters deep or its downward

▲ **PROVEN DESIGN** Shown during testing in 2015, Insight inherited its structure and many of its components from the Phoenix lander, which Lockheed Martin likewise built for NASA.

MARS: NASA / JPL; DOME: CNES / EMMANUEL GRIMAULT; INSIGHT: NASA / JPL / LOCKHEED MARTIN progress is halted, whichever comes first. Reaching 3 meters is enough for good science results. The process is expected to take 30 to 40 days. Once this preparatory work is done — probably around the end of next March — Insight will sit, not moving, just quietly logging its measurements.

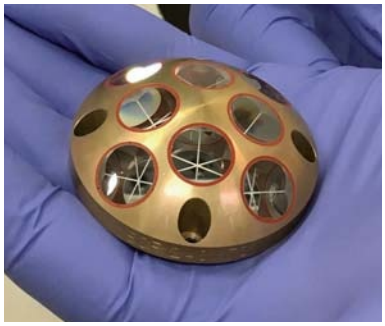
Revolutionary Data

Mars doesn't have continent-scale collisions along crustal plates like Earth does, so it will have fewer, smaller quakes — but it *does* have them. Martian seismic activity is more like the Moon's.

One source of seismicity is internal: The Red Planet is gradually cooling and shrinking, and its brittle outer layer cracks to accommodate the diameter's decrease. Motions along those cracks create marsquakes, and geologists predict that Mars should have about 50 quakes of magnitude 4 or greater every year — about 100 times more activity than the Moon has. Of these events, about 10 could be strong enough for SEIS to detect waves that travel through Mars's core on their way to the detector.

Another source of quaking is external: the abrupt bangs from small asteroid impacts. SEIS won't detect every meteoroid that hits Mars — most will be too small or too distant — but its team expects to record about 20 impact events in the first Martian year. With luck, Mars Reconnaissance Orbiter might be able to spot one or two of the resulting craters,

◀ **TINY TYPE** Attached to Insight is this dime-size microchip inscribed with 2,429,807 personal names submitted to NASA by the public.



◀▼ **FUTURE FEATURE** A team at the Italian Space Agency fabricated eight of these laser retroreflectors for Insight, to be used with a laser altimeter on a possible future Mars orbiter to enable extremely precise measurements of the lander's location.

helping to refine the accuracy of Insight's location estimates.

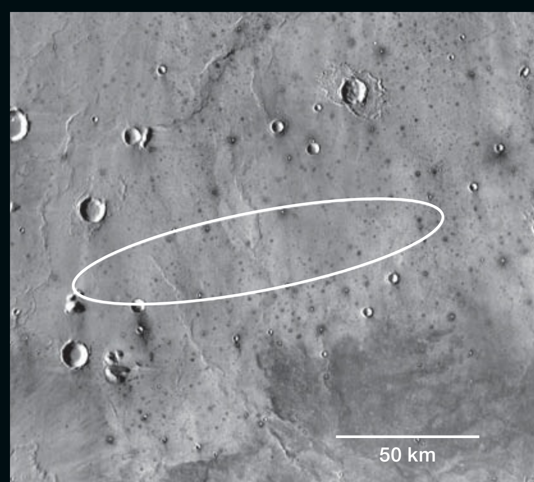
A team at the French space agency CNES (Centre National d'Études Spatiales) designed and built SEIS, which contains two sets of three seismic sensors. One trio uses electronic components to measure ground oscillations as rapid as 50 times per second. These short-period sensors are designed to detect marsquakes and meteorite impacts.

The other set has weights on leaf springs that measure medium- to long-period ground motions — waves that take anywhere from tenths of a second to 10 minutes to pass by Insight. These long-period sensors will feel the slow tides from Phobos's pull. They'll also detect long-period oscillations — akin to the entire planet ringing like a bell — created by pressure waves in the planet's thin atmosphere.

SEIS really only needs to detect a couple of biggish quakes to answer some of the mission's most important questions: How big is the Martian core? How deep is the crust-mantle

MICROCHIP: NASA / JPL / LOCKHEED MARTIN; RETROREFLECTORS: NASA / JPL; MARS MAP: NASA / JPL / USGS / EMILY LAKDAWALLA; TARGET ELLIPSE: NASA / JPL

▼ *Left:* Insight's landing site in Elysium Planitia, chosen near the Martian equator to maximize the sunlight it will receive, is just 600 km (375 mi) from Curiosity's location inside Gale. Blue dots show the locations of future landers, while brown ones mark the sites of those that did not succeed. *Right:* Scientists and engineers examined 22 different landing sites for Insight — all of them within broad Elysium Planitia — before picking one offering flat, nearly rock-free terrain. The lander should end up somewhere inside this target ellipse, which measures 130 by 27 km (81 by 17 miles).



boundary? How fast do quakes propagate through the subsurface? Even if marsquakes are scarce, careful measurement of the repetitive tidal distortion of the crust caused by Phobos (about 1 cm) should be enough to derive the size of the planet's liquid core and perhaps its composition.

Meanwhile, HP³ will measure how fast heat is escaping from the interior. This heat is left over from the planet's formation and also created by the decay of radioactive elements. The rate of its escape affects geologists' understanding of how the planet has evolved over time and also how far underground water has to exist in order to be a liquid instead of ice. HP³ will also monitor how the ground's temperature changes throughout the Martian year and how those swings propagate down below the surface.

Finally, the RISE experiment will probe the interior in a completely different and novel way. Insight has to remain motionless to preserve its measurement precision, and so it doesn't have a steerable radio antenna as most landers do. Instead, it has two fixed antennas pointed roughly east and west. Radio receivers on Earth

▲ A French technician prepares the SEIS instrument for thermal-vacuum testing in 2015.

A Seismic Setback

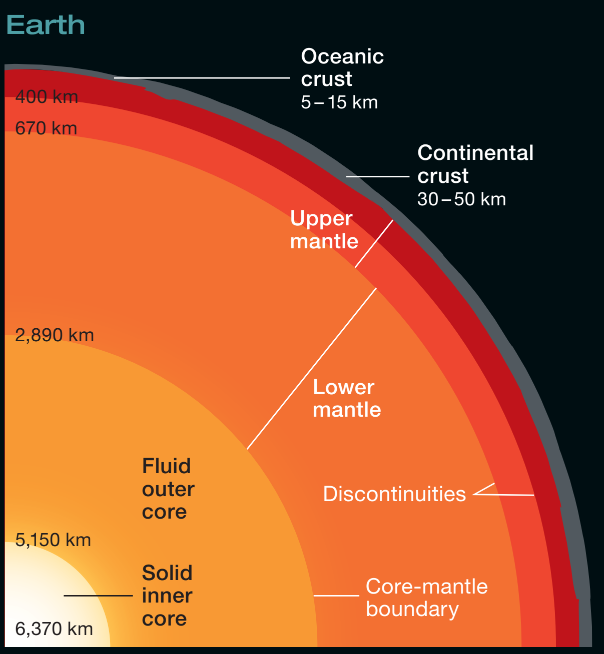
The SEIS seismometer's sensors reside inside a vacuum chamber with a self-leveling, three-legged platform. Those sensors must operate in vacuum in order to be sensitive enough to detect ground motions as small as 2.5×10^{-11} m — about half the Bohr radius of a hydrogen atom. But in 2015, the vacuum chamber developed a leak during testing, and CNES was unable to repair the leak in time for Insight's planned launch in March 2016.

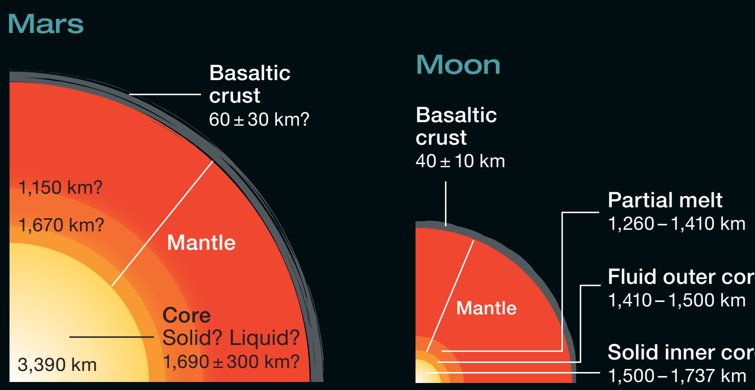
NASA considered canceling Insight entirely, since a launch delay would mean a 2-year postponement that would cause the mission's cost to greatly exceed the relatively economical $425 million budget (excluding launch services) it was allocated. Early in 2016, NASA managers announced that Insight would proceed — but that work on a brand-new design for a vacuum enclosure would switch from CNES to the Jet Propulsion Laboratory.

The delay and new hardware cost $180 million, but ultimately the redesigned vacuum enclosure passed its tests. Insight launched successfully on May 5, 2018, becoming the first interplanetary spacecraft ever launched from Vandenberg Air Force Base on the California coast (*S&T:* Aug. 2018, p. 8).

SEIS INSTRUMENT: CNES / FRÉDÉRIC MALIGNE; EARTH, MARS, MOON CROSS-SECTIONS: LEAH TISCIONE / S&T

▼ **CAUGHT IN THE MIDDLE** Geophysicists want to know whether the interior of Mars has more in common with that of the Moon or of Earth — especially regarding the size of its core, whether it's still partly molten, and for how long the planet might have maintained a global magnetic field.

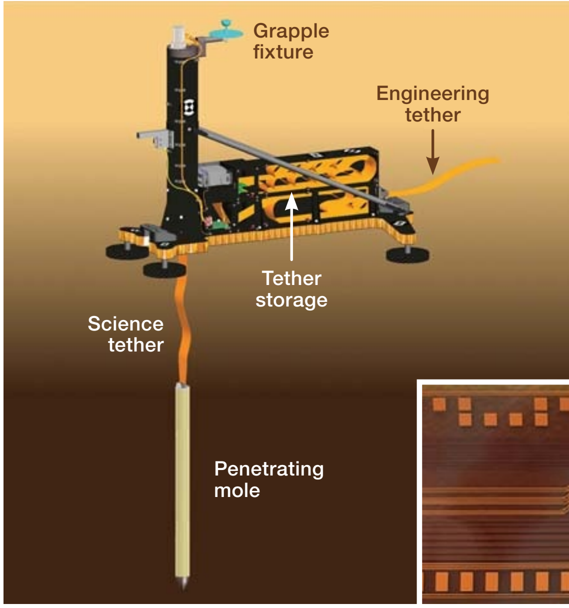




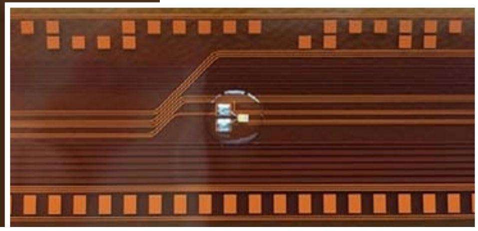
will use subtle Doppler shifts in Insight's transmissions to determine the lander's location to within 10 cm.

RISE scientists will use that positional precision to measure two kinds of cyclic behavior in Mars's rotation. One is *precession* — a change in the orientation of the planet's spin axis. The rate of precession relates to how much mass is concentrated in the core. It's been measured with radio experiments on previous landers (one precessional cycle lasts about 166,000 years), but RISE's measurement will be more precise.

The other is *nutation*, tiny wobbles in the planet's precession due to the gravitational tug of the Sun, Mars's moons, and other major planets on Mars. The size of any nutations will depend on how much of the Martian interior is liquid. No previous mission has been able to detect Mars's rotation with enough precision to observe nutation. If Insight becomes the first, RISE's nutation values should enable geologists to determine how much of the core is molten.



◀ **REEL IT OUT** The Heat Flow and Physical Properties Probe (HP³) consists of a metallic, tube-shaped "mole" attached to the main instrument on the surface by a long, ribbon-like cable. Spring-loaded hammers inside the mole will drive it into the Martian soil — and even through (or around) rocks it might encounter.



▲ **TINY THERMOMETERS** The tether that will trail downward behind the HP³ mole is dotted with 14 sensors, spaced between 23 and 46 cm apart, that can measure temperature differences as small as about 0.01°C (0.02°F).

The Insight Sitter

To gather its data as planned, Insight must hold very still for slightly longer than 1 Martian year (until at least November 2020) so as not to swamp its sensors with spacecraft noise. Other missions to the Red Planet are orbiters and rovers, named for their style of motion. If we were to name this one based on its identifying activity, it would be the Insight sitter.

It might not be the most dazzling assignment, but not every Mars mission can be a celebrity rover. The scientific payoff from Insight will take time, and our patience will be rewarded with answers to fundamental questions about Mars's interior — answers that will help us understand why our own planet is so special.

■ Contributing Editor **EMILY LAKDAWALLA** is Senior Editor and Planetary Evangelist for The Planetary Society and was recently named editor of its bimonthly magazine, *The Planetary Report.*

Hand-Me-Down Hardware

Although Insight's grapple is new, the rest of its robotic arm has been on the shelf since NASA cancelled the lander intended for the Mars Surveyor 2001 mission. In fact, the 20-year-old arm still bears the scoop that Surveyor would have used. Insight has no need for the scoop, but its existence will likely be a temptation to the science team if the mission achieves all its primary goals with the spacecraft and arm still in good shape.

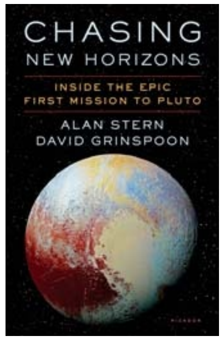
◀ Insight's robotic arm, left over from a NASA lander that was never flown, includes a small scoop (arrowed) that might be used during the mission to help characterize the dust and small rocks at the landing site.

HP³ SCHEMATIC: GERMAN SPACE AGENCY; TEMPERATURE SENSOR: GERMAN SPACE AGENCY; ROBOTIC ARM: NASA / JPL

The "Last First" Reveal

CHASING NEW HORIZONS: *Inside the Epic First Mission to Pluto*

Alan Stern and David Grinspoon
Picador, 2018
320 pages, ISBN 9781250098962
$28.00, hardcover.



THERE'S A MOMENT in every planetary mission when human drama takes center stage. For the New Horizons arrival at Pluto, it came when radio signals resumed after the flyby on July 14, 2015. Missions Operations Manager Alice Bowman polled the team for the spacecraft's condition after nine hours of radio silence. All managers checked in successfully. In a moment of pride, she turned to everyone with a big smile and said, "PI, this is MOM on Pluto One. We have a healthy spacecraft. We've recorded data at the Pluto system, and we're outbound from Pluto."

A crowd of scientists and observers broke into wild applause and cheering. It was a stunning moment made more radiant by the joy and relief on the team members' faces as they realized they'd "done it." They'd explored Pluto and the spacecraft had lived to tell about it.

> The New Horizons mission . . . is the "last first" reveal of an entirely new planet and a new realm of the solar system.

The flyby wasn't simply the culmination of nine years of waiting while the spacecraft got to Pluto. It was the crowning moment of nearly 26 years of work that started soon after Alan Stern and his Pluto colleagues earned their PhDs. They set out on a decades-long path of setbacks and cancellations, mission restarts, and incredible competition to get their spacecraft flown.

In *Chasing New Horizons: Inside the Epic First Mission to Pluto*, authors Alan Stern and David Grinspoon, who's a Contributing Editor of this magazine, focus on the human story that led up to the events of July 2015. It begins with Stern's dream of going to Pluto and follows through to the triumphant Pluto flyby. Grinspoon's expert storytelling mixes with Stern's insights to create a compelling tale. It brings the reader along as the team met and exceeded the challenges of getting a mission planned, approved, launched, and executed. The story provides a visceral understanding of how it feels to be part of such an enterprise.

Chasing New Horizons unveils the shifting political landscapes navigated by the team. There are stories of bizarre meetings with NASA administrators, unforeseen roadblocks, and endless funding challenges. Just to propel themselves through the maze of requirements (from proposal to assembly to launch) required the team to be nimble and tough. "We had obstacles thrown at us all along the way," said Stern. "They were both technological and political. Some we expected, others — especially from within the Agency — felt like we were being played with. But, we persisted, and we got to Pluto."

Stern commanded a disciplined group able to innovate and persevere through multiple setbacks. The result was a tight-knit team that devised an ingenious spacecraft and delivered incredible achievements. According to Grinspoon, youth was an asset. "Alan was pretty young and inexperienced when the quest for this mission began," Grinspoon notes. "He was certainly more experienced than most other freshly minted PhDs, but still had to learn an awful lot on the fly. As someone comments in the book, it's probably a good thing that they didn't anticipate all the setbacks from the beginning. Sometimes it's better not to know everything that is in store!"

Several of the human-interest moments caught me by surprise, such as the description of the day the spacecraft arrived at the launch site. "As Alan stepped out onto the tarmac, Chuck [Tatro, the New Horizons launch-site manager] put his hand out to shake Alan's and said, "Dr. Stern, welcome to the launch site." The words hit Stern like a ton of bricks. "After all these years, from 1989 to 2005, we really, finally had a Pluto spacecraft at its launch site. We were really about to fly across the solar system and explore the farthest worlds in history. The reality of the impending launch and decade-long flight across the solar system hit me when Chuck said that. It literally sent a shiver up my spine!"

Chasing New Horizons is a story that will resonate with all readers. The mission itself is already among the greats of planetary exploration history. "I think it will be mentioned along with the Mariners, Pioneers, and Voyagers as an essential part of the first phase of humanity's expansion beyond Earth," says Grinspoon. "It's the 'last first' reveal of an entirely new planet and a new realm of the solar system."

■ **CAROLYN COLLINS PETERSEN** is a science writer with several books to her credit and a producer of science videos.

OBSERVING
December 2018

AKIRA FUJII

2–4 EARLY MORNING: Venus and Spica are some 7° apart in the southeast. Watch as the waning crescent Moon approaches the pair. On the 2nd, the three celestial bodies form a shallow triangle, while on the 3rd, the triangle tightens, with the Moon above Venus and upper left of Spica. The Moon and Spica bookend the Morning Star on the 4th.

2 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:53 p.m. EST (6:53 p.m. PST); see page 51.

5 EVENING: Algol shines at minimum brightness for roughly two hours centered at 6:42 p.m. EST.

13–14 ALL NIGHT: The Geminid meteor shower is expected to peak early in the morning of the 14th. As always with this long-lived and prolific shower, look for meteors both in the mornings preceding and those following the peak. The waxing crescent Moon will not interfere with observing as it sets several hours before the radiant climbs to its highest.

14 EVENING: The Moon and Mars are less than 4° apart as they emerge in twilight; watch as they set together in the west before midnight.

19 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:47 p.m. PST.

20–21 ALL NIGHT: The almost-full Moon is in the Hyades.

21 DAWN: Try to catch Jupiter and Mercury, less than 1° separating the solar system's largest and smallest planets, low in the southeast before the Sun rises.

21 THE LONGEST NIGHT OF THE YEAR in the Northern Hemisphere. Winter begins at the solstice, at 5:23 p.m. EST (2:23 p.m. PST; 22:23 UT).

22 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:36 p.m. EST (8:36 p.m. PST).

24–25 ALL NIGHT: The waning gibbous Moon starts the evening around ½° from the Beehive Cluster (M44) in Cancer; by sunrise, the Moon has increased the separation to 4°.

29 DAWN: The last-quarter Moon visits Virgo again. It will be some 2° from Porrima, or Gamma (γ) Virginis.

Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.
NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

NEW MOON
December 7
07:20 UT

FIRST QUARTER
December 15
11:49 UT

FULL MOON
December 22
17:49 UT

LAST QUARTER
December 29
09:34 UT

DISTANCES

Apogee December 12, 12h UT
405,177 km Diameter 29′ 29″

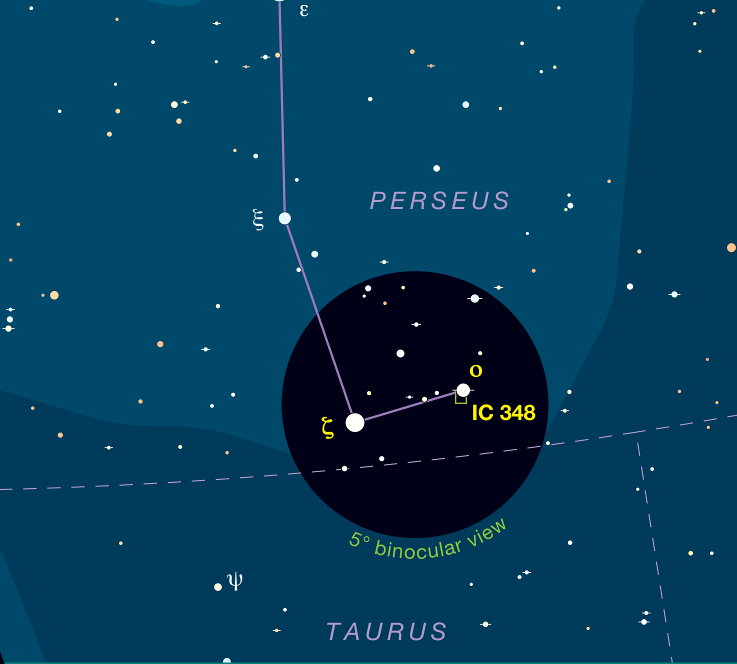
Perigee December 24, 10h UT
361,062 km Diameter 33′ 06″

FAVORABLE LIBRATIONS

- Abel Crater December 10
- Lavoisier E Crater December 22
- Ulugh Beigh Crater December 23
- Hagecius Crater December 25

Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.



Binocular Highlight by Mathew Wedel

The True and the False Atik

Atik is Arabic for "the shoulder," and it's traditionally been the name for a bright star about 9° north of the Pleiades. But which star? Some sources — including my beloved *Pocket Sky Atlas* — apply the name to **Zeta (ζ) Persei**, whereas others identify **Omicron (ο) Persei**, 2° west of Zeta, as Atik. Even that's complicated, because Omicron Persei is a multiple system with at least three stars. In 2016 the International Astronomical Union laid the matter to rest: Omicron Persei A is Atik.

Why am I going on about this? It's because I want you to go look at both Zeta and Omicron Persei, and the surrounding Milky Way. Zeta is a superluminous *B*1 supergiant, lying roughly 1,000 light-years away. At the tender age of 9 million years, it has already started shutting down hydrogen fusion in its core, and sometime in the next million years it will blow itself apart in a Type II supernova. Omicron Persei A is also a *B*1 giant, somewhat smaller than Zeta, but likewise fated to go out in a blaze of glory.

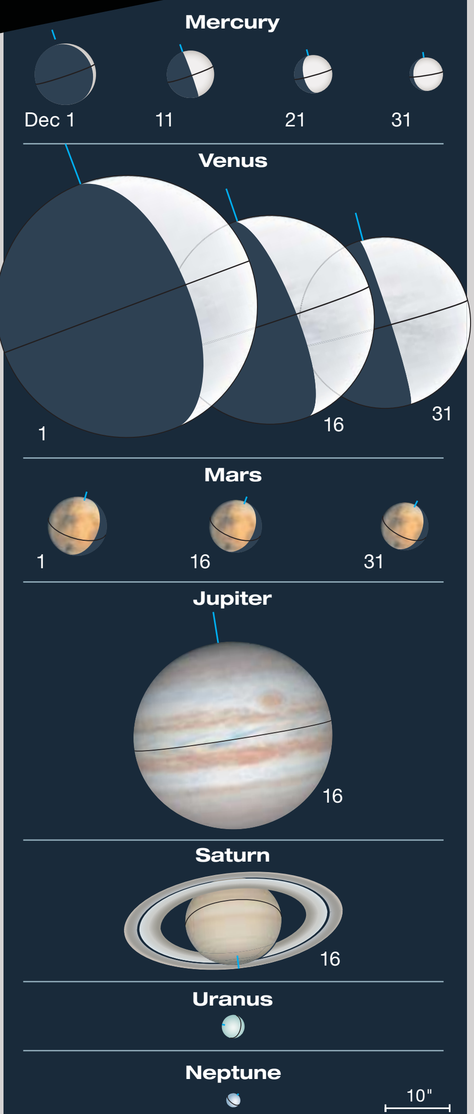
We won't be around for that, but there's plenty to see right now. Look for several chains of stars radiating away from Zeta Persei to the northwest. These rays of stars are just chance alignments, but they're pretty, and they're spangled with orange and yellow *K*-class giants. Then have a close look at Omicron Persei. A scant 10′ to the southeast lies the tiny star-forming region **IC 348**. At 7th magnitude, this compact wisp of light should be visible in most instruments under good conditions — if you can pull it out of the glare of Atik. Stars are being born there, right now, and that is always a momentous and humbling thought.

■ MATT WEDEL is bushwhacking through the hinterlands of Perseus. He's expected back any day now.

WHEN TO USE THE MAP

Late Oct	Midnight*
Early Nov	10 p.m.
Late Nov	9 p.m.
Early Dec	8 p.m.
Late Dec	7 p.m.

*Daylight-saving time



PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY **Mercury:** visible at dawn after December 3rd • **Venus:** visible at dawn all month • **Mars:** visible at dusk, sets before midnight • **Jupiter:** visible at dawn after December 7th • **Saturn:** visible at dusk through December 15th

December Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^{h}\,26.9^{m}$	–21° 43′	—	–26.8	32′ 26″	—	0.986
	31	$18^{h}\,39.1^{m}$	–23° 08′	—	–26.8	32′ 32″	—	0.983
Mercury	1	$15^{h}\,54.0^{m}$	–18° 17′	8° Mo	+3.0	9.6″	6%	0.703
	11	$15^{h}\,46.8^{m}$	–17° 13′	20° Mo	–0.3	7.4″	48%	0.909
	21	$16^{h}\,27.6^{m}$	–20° 09′	20° Mo	–0.5	6.0″	76%	1.128
	31	$17^{h}\,25.8^{m}$	–22° 57′	17° Mo	–0.4	5.2″	88%	1.284
Venus	1	$13^{h}\,49.2^{m}$	–9° 48′	40° Mo	–4.9	40.7″	26%	0.410
	11	$14^{h}\,14.4^{m}$	–10° 50′	44° Mo	–4.8	34.8″	34%	0.479
	21	$14^{h}\,46.2^{m}$	–12° 44′	46° Mo	–4.7	30.2″	41%	0.552
	31	$15^{h}\,23.0^{m}$	–15° 01′	47° Mo	–4.6	26.6″	47%	0.627
Mars	1	$22^{h}\,44.9^{m}$	–9° 11′	91° Ev	0.0	9.3″	86%	1.009
	16	$23^{h}\,20.7^{m}$	–5° 00′	85° Ev	+0.2	8.3″	87%	1.129
	31	$23^{h}\,56.9^{m}$	–0° 41′	80° Ev	+0.4	7.5″	87%	1.253
Jupiter	1	$16^{h}\,11.6^{m}$	–2° 26′	4° Mo	–1.7	31.1″	100%	6.342
	31	$16^{h}\,39.4^{m}$	–21° 31′	28° Mo	–1.8	31.8″	100%	6.201
Saturn	1	$18^{h}\,32.8^{m}$	–22° 42′	29° Ev	+0.5	15.2″	100%	10.912
	31	$18^{h}\,47.7^{m}$	–22° 30′	2° Ev	+0.5	15.1″	100%	11.043
Uranus	16	$1^{h}\,46.9^{m}$	+10° 27′	125° Ev	+5.7	3.7″	100%	19.285
Neptune	16	$23^{h}\,00.9^{m}$	–7° 22′	80° Ev	+7.9	2.3″	100%	30.097

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^{h} Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. is 149,597,871 kilometers, or 92,955,807 international miles.) For other dates, see skyandtelescope.com/almanac.

The Sun and planets are positioned for mid-December; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

Rains of Fire

Meteor showers elicit wonder in one and all.

Guy Ottewell has quoted Manilius: Nunquam futilibus excanduit ignibus aether — *"The ether never blazed with futile fires" — and Guy quite rightly added, "That is to say: all meteors mean something." I agree. Every meteor means beauty, surprise, wonder, and a stirring of thought for its fortunate observer.*

Fred Schaaf, *The Starry Room*

▲ **GEMINIDS RAIN ON THE TEIDE VOLCANO** The image is a composite of photos taken in the Canary Islands over a period of two hours during the peak of the shower in December 2013.

JUAN CARLOS CASADO

You could be reading these words as early as mid-October. If so, get ready: From October 20th to 22nd, you may get the chance to see the Orionid meteor shower — flaming debris from past returns of Halley's Comet. Reading this in early November? Look for few but possibly fireball-bright Taurids as the Bull ascends in the east and southeast through the evenings, reaching its highest in the middle of the night. Or around November 17th you might spot a few meteors from the usually mild output — but at thrice-a-century intervals sky-filling downpours — of the Leonid meteor shower. What's most meteorically important of all? Don't miss December's Geminid meteor shower this year (see p. 48).

A starry sky of all radiants. Only a few of the important meteor showers occur in the first half of the year. Milton was exquisitely correct when he wrote, *"Swift as a shooting star / In Autumn thwarts the night."* Note, by the way, that "thwart" here doesn't just mean defeat or overcome darkness; it also means move across (as in the word "athwart").

But take a look at our December all-sky map. A *radiant* is the location within a constellation from which all the meteors of a particular shower appear to shoot. If we list the constellations that contain the radiants of what are arguably the 12 most important annual meteor showers we find that all of them — except Leo — are above the horizon at the time of our map.

If you're a devotee of meteor showers you'll find that the star fields you stare at while searching for meteors become engraved in your mind like none other.

The Passing of a Meteor and a Man. Although I think meteors always uplift our hearts by virtue of their wonder, they also stir other poignant feelings — or help us connect to those feelings. Even those of us who aren't superstitious can note coincidences. I hadn't been to the South Jersey Astronomy Club field at Belleplain State Forest for quite a while, and when I went back I and fellow club members had a good evening of observing with a group of my college students. One of our highlights was an unusually slow, long-lasting, and flaring meteor. The next day, we learned that one of the club's most cherished members — a man with whom we had shared the heavens for decades at that field on many a glorious night — had died. He passed away at possibly just about the same time we saw the meteor.

Meteors and human lives. Can something as brief as a meteor mean so much to us? Well, in this column I once noted that decades ago I had started trying to time meteors with a stopwatch and found I couldn't often hit the button twice in less than about one-seventh of a second. I pointed out that this was about the length of a fairly long human life in the timing of Carl Sagan's "Cosmic Calendar," in which we set the 13.8 billion-year life of the universe as equal to a single calendar year. I wrote that even one-seventh of a second could be long enough to have a sudden wonderful thought or feeling, or to get a single swift glance at something awesome.

But only recently did I suddenly think of a wondrous natural phenomenon that can indeed last as little as $1/7$ of a second: a meteor. That's a human life in cosmic terms. Even so, the most awesome meteor I've ever seen was timed by another observer (with a stopwatch) as lasting 10.5 seconds. Such a meteor's duration would be roughly as long as all recorded human history in the Cosmic Calendar.

■ **FRED SCHAAF** observed his first meteor showers, including the Perseids first of all, when he was 8 or 9 years old.

To find out what's visible in the sky from your location, go to skypub.com/almanac.

Conjunction Couplet

As we head into the darkest time of the year, the planets keep us busy with their nightly capers.

In the final month of 2018, the planets offer an interesting assortment of sights at both dusk and dawn — including two very close planetary conjunctions. At dusk, Saturn is very low in the southwest until it drops completely from view around mid-month. Mars remains well-positioned, standing at its highest in the south at nightfall and passing extremely close to dim Neptune early in the month. In the dawn sky, Venus is spectacularly bright and impressively high. Very far to the lower left of Venus, Mercury climbs to a good apparition in the southeast, followed by brighter Jupiter, which closely passes Mercury a few days before Christmas.

DUSK ONLY

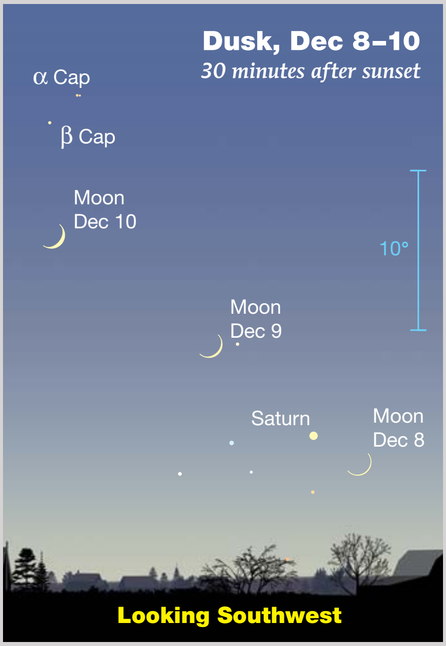
Saturn starts December setting about two hours after the Sun. By the end of the first week of the month the magnitude-0.5 planet stands only about 8° or 9° high in the southwest just 30 minutes after sunset (use binoculars). By around mid-month the ringed planet has fallen too deep into the Sun's afterglow to find. This year, 2018, is one of only two between 1961 and 2040 in which Saturn doesn't reach conjunction with the Sun — but it will on January 2, 2019.

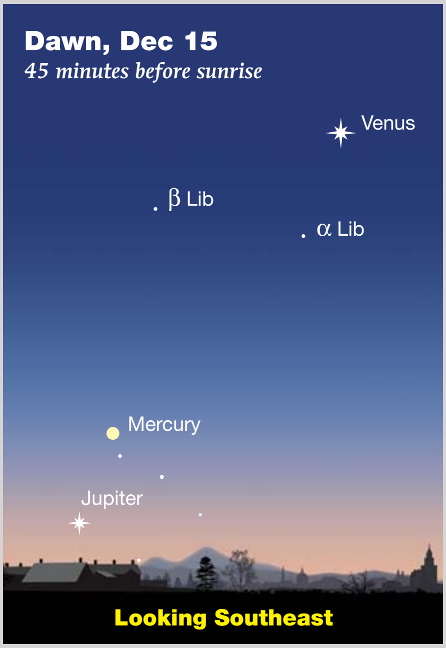
DUSK TO MIDNIGHT

Mars races east from Aquarius into Pisces in December and sets at almost the same time — around 11:30 p.m. — every night during the month. The time that Mars reaches the meridian in the south does change a little, though, from about 6 p.m. to 5:15 p.m. — but remains excellent, around nightfall, throughout December. Unfortunately, even having Mars at its highest doesn't guarantee seeing much on its surface in amateur telescopes, because the planet dwindles from about 9″ to 7½″ in diameter this month. Mars, like a fading ember, also decreases in brightness, from magnitude −0.1 to +0.5.

One special telescopic sight to look for this month is an ultra-close conjunction of Mars and **Neptune**. The two are closest together — just 2′ apart — around 15 UT (10 a.m. EST) on December 7th. In the Americas on the evening of December 6th, the separation between the planets is a little more than 20′ shortly after sunset, and on the evening of the 7th they are even closer, a mere 15′ apart.

Uranus, on the border of Pisces and Aries, is highest a few hours after evening twilight ends. Finder charts for it and Neptune are in the September issue, pages 48–49.



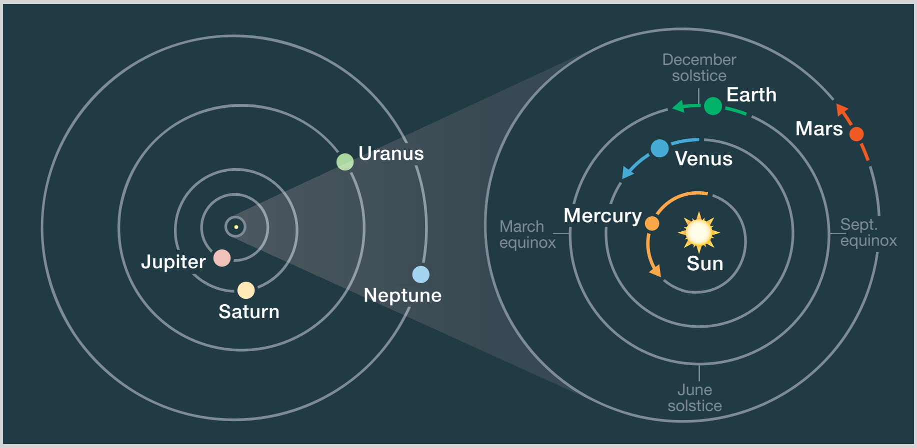


PRE-DAWN TO DAWN

Venus veritably vaulted up out of the dawn during November, its sunrise altitude increasing from about 5° to 32°. But in December the brilliant planet gets only a little higher, reaching its peak sunrise altitude of 33° on the 13th for observers at latitude 40° north. Venus is even a little lower on December 31st than it was on December 1st. The planet dims a bit from its maximum brightness of –4.9, ending the month and year at –4.6. During December the angular diameter of Venus decreases from 41″ to 26″, and its phase increases from 25% to 46% illuminated. Venus will reach greatest elongation from the Sun on January 6, 2019.

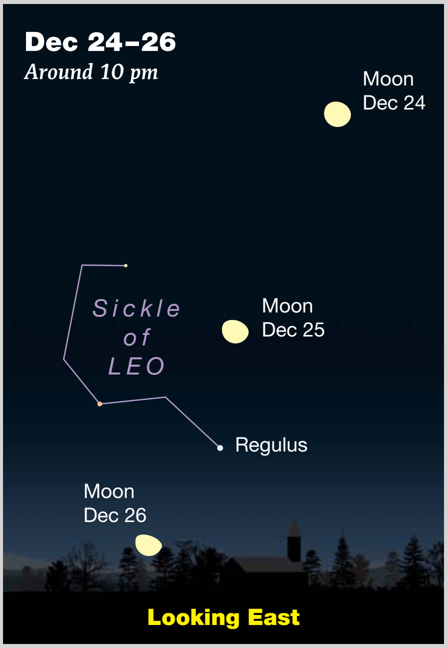
Mercury was at inferior conjunction with the Sun on November 27th, but in December it leaps up into an excellent morning apparition. Too dim to see at first, Mercury kindles to magnitude +0.5 by December 6th and +0.0 by the 8th. By December 15th, the fleet world is already at a greatest elongation of 21° from the Sun and rises almost 1¾ hours before the Sun (it also appears more than 60% lit by then). Mercury's magnitude from December 12th to the end of the month hovers around –0.4 or –0.5. But what's really exciting is its close conjunction this month with an even brighter planet, Jupiter.

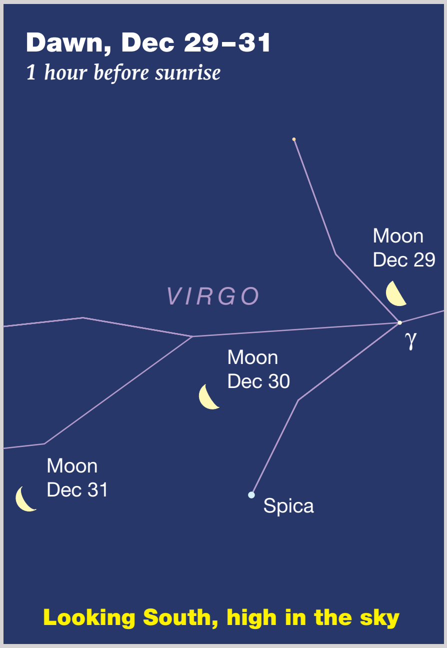
Jupiter was at conjunction with the Sun on November 26th and trails Mercury up into the dawn sky in December. Jupiter starts rising about an hour before the Sun around December 12th, with its –1.7-magnitude point of light more than three magnitudes fainter than mighty Venus. Jupiter was in Libra before it was lost in the solar glare, but in early December the giant planet comes back out in Scorpius. At mid-month Jupiter marches into Ophiuchus and on December 20th passes 5° upper left of the star Antares. Very low in the southeast on the morning of December 21st, the biggest planet in the solar system, Jupiter, is less than 1° from the smallest planet, Mercury. Jupiter appears 31″ across, Mercury 6″; Jupiter is fully lit, Mercury ¾ lit. Note also the much greater surface brightness of Mercury compared to Jupiter. In the final days of the year, Mercury continues to appear lower and Jupiter higher.



ORBITS OF THE PLANETS
The curved arrows show each planet's movement during December. The outer planets don't change position enough in a month to notice at this scale.

▼ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date.





SUN AND MOON

The Sun reaches the winter solstice at 5:23 p.m. EST on December 21st, ushering in winter in the Northern Hemisphere and summer in the Southern Hemisphere.

The Moon is a waning crescent forming a triangle with Venus and Spica in the southeast at dawn on December 3rd. The waxing lunar crescent is about 4° lower right of Saturn at dusk on December 8th. The first-quarter Moon is 4° below Mars on the evening of December 14th. The Moon is waning gibbous as it glides past Regulus between December 25 and 26. The waxing crescent Moon is almost 7° above or upper left of Spica at dawn on December 30th.

■ **FRED SCHAAF** is the author of *The Starry Room*, published 30 years ago by John Wiley & Sons and republished 16 years ago by Dover Publications.

You're unlikely to see more than one meteor every few minutes even at the peak of the Geminid shower. If you could see a morning's worth of meteors simultaneously, however, the view would look something like the one captured in this 3-hour time-lapse image of the sky above Yunnan Province, China, on December 14, 2012.

JEFF DAI / STOCKTREK IMAGES / GETTY IMAGES

An Unusual Parent

The familiar Geminid meteor shower springs from an unfamiliar source.

The Geminid meteor shower, which is predicted to peak around 12:30 UT (7:30 a.m. EST, 4:30 a.m. PST) December 14th, is one of two major showers tied to asteroidal, rather than cometary, sources. Although parent to one of the better-known meteor streams, asteroid 3200 Phaethon remains a bit of a mystery object. Phaethon is a rare type of asteroid called a *rock comet*. Like a normal comet, it ejects or outgases material, but that material consists of rock dust rather than the ice-related vapors typical of comets. Radiation pressure sweeps Phaethon's rocky bits off the main body to contribute to a comet-like tail.

With a perihelion distance of 0.14 a.u., Phaethon comes closer to the Sun than any other named asteroid. These close approaches mean it endures high surface temperatures, which probably crack Phaethon's crust to release even more grit and granules. That's the idea, anyway. Astronomers aren't sure how Phaethon generates enough dust to make the Geminid meteor shower so productive year after year.

The best meteor counts should come early in the morning on December 14th: Meteor counts are highest when a shower's radiant is highest in the sky. For observers watching from mid-northern latitudes, the radiant, which lies near 2nd-magnitude Castor at the time of maximum, rises about 45 minutes after sunset and stands about one-third up the sky by 9 p.m. local standard time. It culminates about 2:00 a.m., setting the stage for a perfect pre-dawn meteor extravaganza.

This early-evening rise is responsible for the high number of *earthgrazers* — long, bright fireballs that appear to emanate from the horizon — associated with the shower. Earthgrazers travel at slow or medium speeds, can reach a brightness of magnitude –5 or more, and often produce dramatic stuttering explosions if they fail to escape the atmosphere. These are the meteors that make the evening news.

It's a good idea to go out on the evening of the 14th as well, as the shower's maximum is broad, with peak rates lasting almost a full day. You'll have to share your evening with the waxing crescent Moon, since it doesn't set until close to midnight, so try to keep it at your back as you observe. No moonlight will interfere with morning observations.

The International Meteor Organization (IMO) predicts a zenithal hourly rate (ZHR) of around 120 this year. The ZHR is the number of meteors you would see in an hour under very dark skies if the shower's radiant stood directly overhead. For the Geminids, fainter, telescopic meteors are most abundant a day ahead of peak, and some of the brighter meteors tend to appear after peak. You may see the occasional shower meteor during the week before and after the peak as well.

While the radiant is better placed for observers in the Northern Hemisphere, offering higher overall counts, the Geminids can also be a good shower for skywatchers in the Southern Hemisphere. The radiant stays low, reaching approximately 30° in altitude as it crosses the meridian, for viewers at mid-southern latitudes. That limits the number of visible meteors to about half of what can be seen from the Northern Hemisphere.

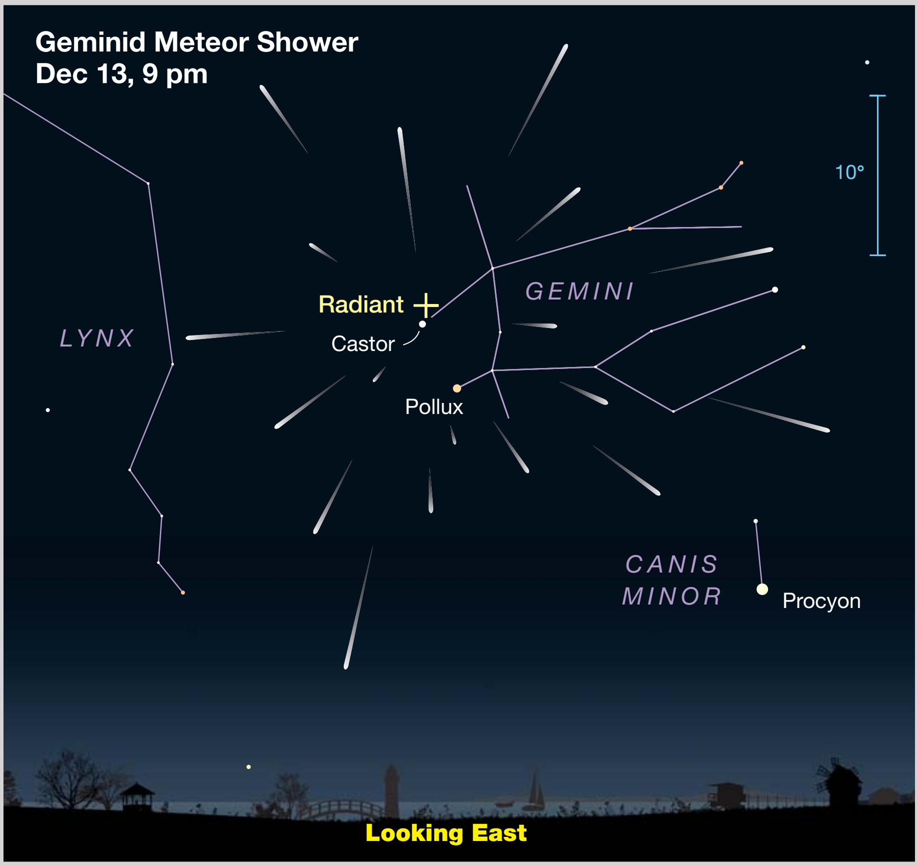
Make a Count

Despite being one of the more productive and reliable of the major meteor showers, the Geminids remain a somewhat under-reported event. This may have something to do with the shower's timing. For observers in colder, northern climates, the temptation to go (or stay) inside where it's warm can be strong. This is too bad, as the Geminids often outperform the more famous summer Perseids.

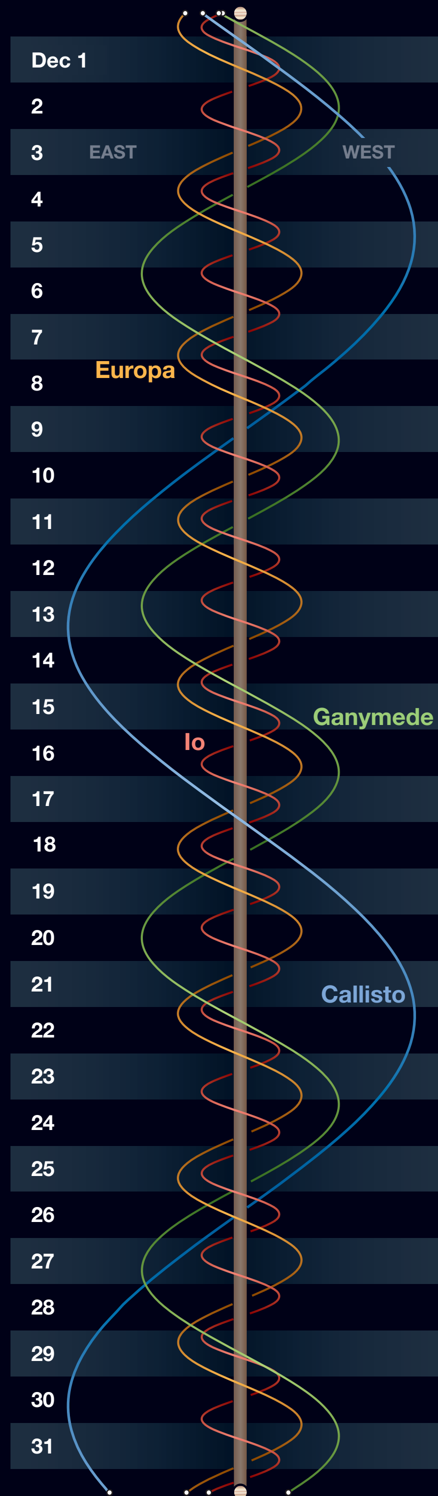
But if you're willing to spend at least one hour outside in December and like to stay up late or get up very early, you can do a scientific meteor count. Dress for the weather (no meteor shower is worth frostbite or even frostnip) and make sure you have a comfortable lounger or chair. As far as observing equipment, you'll need an accurate watch, a dim red light, pencils, and paper; a voice recorder can help. You'll need to follow a standardized method for recording your sky conditions and the actual number of meteors seen for your records to be useful to the IMO. For more detailed instructions, see **imo.net/visual/major**.

If you're doing a formal count and spot a light streak that doesn't seem to emanate from the Geminid radiant, you might have caught an erratic or a meteor associated with one of the season's minor showers, such as the Monocerotids, Sigma Hydrids, Puppid-Velids, or even the Northern Taurids.

▼ The radiant for the Geminid meteor shower is located near Alpha Geminorum, more familiarly known as Castor. To determine if a meteor is a Geminid, trace its path backward to its point of origin. If you end up at a point well away from Castor, you've spotted either an erratic or a meteor belonging to another winter shower.



Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

Say Hello to Hebe

WORSHIPPED AS JUVENTAS in ancient Rome, the goddess Hebe makes only fleeting appearances in the myths of ancient Greece. From Hesiod, we learn she's the offspring of Hera and Zeus. Ovid portrays her as the personification of youth and rejuvenation, capable of making even an old man young again. In Homer's *Iliad*, she appears at a war council, filling golden cups with nectar for the gods while they debate the ongoing Trojan War.

Fortunately for us, Hebe's appearance in the night sky in the form of a main-belt asteroid lasts longer than a few sentences. The stony asteroid 6 Hebe, discovered in 1847, spends most of December looping across Monoceros before crossing into Orion on the 29th. Observing conditions improve the deeper into the calendar we go. For those observing from around latitude 40° north in mid-November, Hebe peeks over the horizon about 9 p.m. local time and culminates about 3 a.m. A month later, Hebe rises about 6:30 p.m. and culminates about 1 a.m.

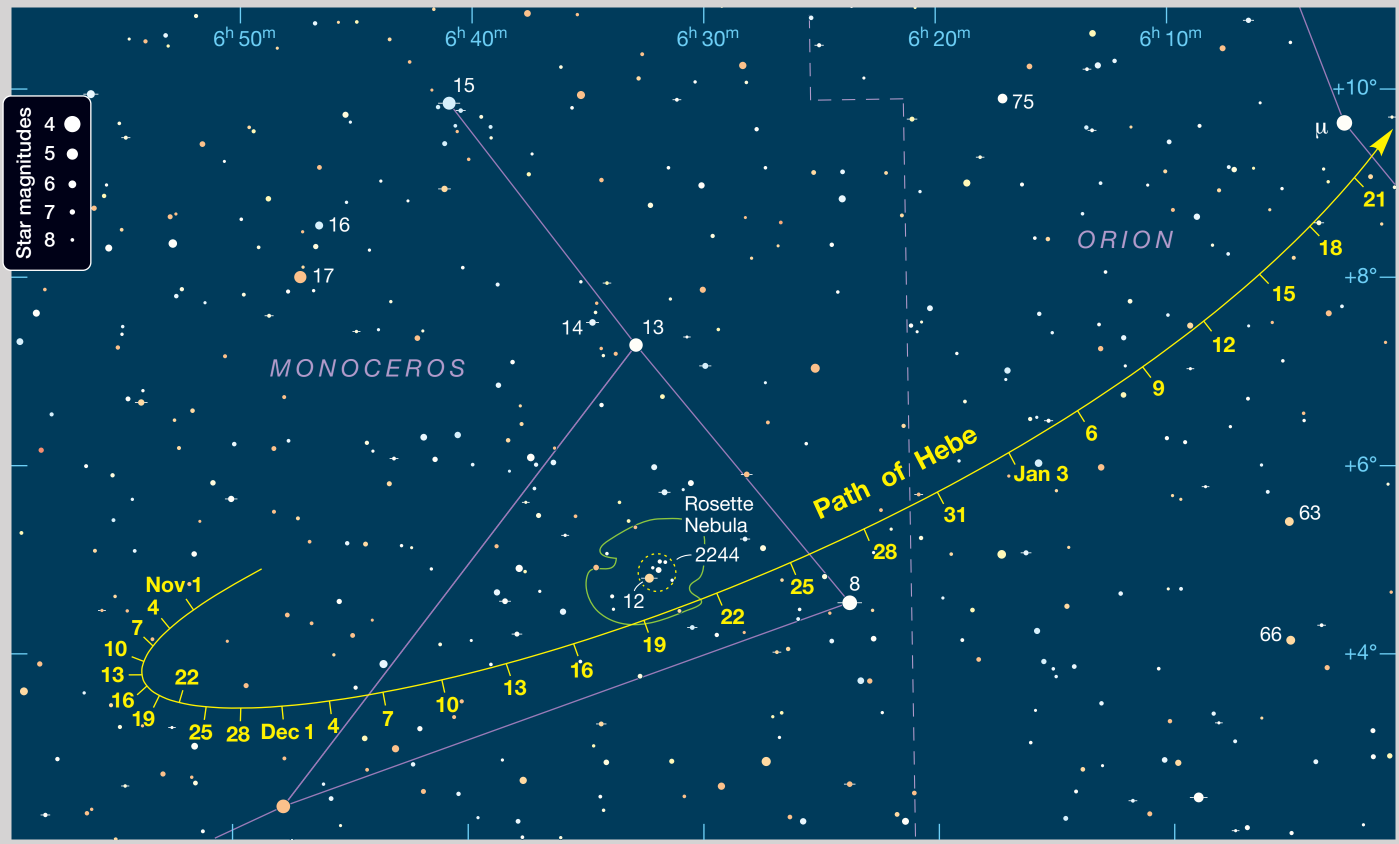
Hebe reaches opposition the evening of December 27th (2:00 UT December 28th), when it rises about 5:30 p.m. and culminates at midnight. Closest approach comes more than a week earlier, at 15:00 UT December 20th, when Hebe will be 1.26 a.u. from Earth.

Hebe is the fifth-brightest asteroid, so while it may not shine as brilliantly as would a goddess of youth, it's not an exceptionally dim object. It rises in brightness from magnitude 9.5 on November 1st to 8.4 on the nights of December 25th and 26th. It falls off in brightness each night afterward, dimming to 9.1 by the end of January.

Although Monoceros isn't known as the most picturesque piece of sky, Hebe finds itself in good company in December. On the 20th, it's near NGC 2244, the open cluster at the heart of the Rosette Nebula. And on the 25th, it passes the double star 8 Monocerotis.

Until recently, scientists suspected that roughly 34% of the meteorites that impact Earth came from Hebe. However, observations taken in 2014 with ESO's Very Large Telescope have again raised the question as to the origin of H chondrites (the H signifies "high" iron content, about 25–35% nickel-iron). Observations were acquired at four different epochs between December 8–12, 2014. The resultant 3D models suggest that even the largest depression (impact basin) on Hebe is too small to account for all Earth's H chondrites.

▼ The date ticks on Hebe's path are plotted for 0^h Universal Time (on the evening of the previous date in the Americas). Put a dot at the date and time you plan to observe, and star-hop there from 8 Monocerotis or 8 Monocerotis.



Action at Jupiter

JUPITER, MISSING IN ACTION since around November 7th, reappears in the morning sky this month. You may be able to tease it out of the twilight with binoculars as early as December 8th, when it rises about 30 minutes before the Sun, but realistically, observing it remains something of a challenge all month. Jupiter's bright enough, shining at magnitude –1.7 and –1.8 for the balance of December, but even on the 31st it's only about 12° high some 45 minutes before dawn. Jove grows just a tick heftier this month, fattening from 31″ to 32″ by New Year's Eve.

As observing conditions improve, it will be easier to detect Jupiter's moons. Any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on page 49 to identify them at any date and time.

All of the December interactions between Jupiter and its satellites and their shadows are tabulated in the table to the right. Find events timed for when Jupiter is at its highest in the early morning hours.

Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

Dec. 1, 2:24, 12:20, 22:16; **2,** 8:12, 18:08; **3,** 4:03, 13:59, 23:55; **4,** 9:51, 19:47; **5,** 5:43, 15:38; **6,** 1:34, 11:30, 21:26; **7,** 7:22, 17:17; **8,** 3:13, 13:09, 23:05; **9,** 9:01, 18:57; **10,** 4:52, 14:48; **11,** 0:44, 10:40, 20:36; **12,** 6:31, 16:27; **13,** 2:23, 12:19, 22:15; **14,** 8:10, 18:06; **15,** 4:02, 13:58, 23:54; **16,** 9:50, 19:45; **17,** 5:41, 15:37; **18,** 1:33, 11:29, 21:24; **19,** 7:20, 17:16; **20,** 3:12, 13:08, 23:03; **21,** 8:59, 18:55; **22,** 4:51, 14:47; **23,** 0:42, 10:38, 20:34; **24,** 6:30, 16:26; **25,** 2:21, 12:17, 22:13; **26,** 8:09, 18:05; **27,** 4:00, 13:56, 23:52; **28,** 9:48, 19:44; **29,** 5:39, 15:35; **30,** 1:31, 11:27, 21:23; **31,** 7:18, 17:14.

Minima of Algol

Nov.	UT	Dec.	UT
1	13:54	3	2:53
4	10:43	5	23:42
7	7:32	8	20:31
10	4:21	11	17:20
13	1:10	14	14:09
15	21:59	17	10:58
18	18:48	20	7:47
21	15:37	23	4:36
24	12:26	26	1:26
27	9:15	28	22:15
30	6:04	31	19:04

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.5540+ 2.86732400*E*, where *E* is any integer. For a comparison-star chart and more info, see **skyandtelescope.com/algol**.

Phenomena of Jupiter's Moons, December 2018

Dec. 1	4:44	I.Sh.I
	4:48	I.Tr.I
	6:54	I.Sh.E
	6:59	I.Tr.E
	15:07	II.Sh.I
	15:17	II.Tr.I
	17:27	II.Sh.E
	17:39	II.Tr.E
Dec. 2	2:04	I.Ec.D
	4:22	I.Oc.R
	23:12	I.Sh.I
	23:18	I.Tr.I
Dec. 3	1:22	I.Sh.E
	1:30	I.Tr.E
	9:17	II.Ec.D
	11:53	II.Oc.R
	20:33	I.Ec.D
	22:52	I.Oc.R
Dec. 4	6:46	III.Ec.D
	9:21	III.Oc.R
	17:41	I.Sh.I
	17:49	I.Tr.I
	19:51	I.Sh.E
	20:00	I.Tr.E
Dec. 5	4:25	II.Sh.I
	4:42	II.Tr.I
	6:44	II.Sh.E
	7:04	II.Tr.E
	15:01	I.Ec.D
	17:22	I.Oc.R
Dec. 6	12:09	I.Sh.I
	12:19	I.Tr.I
	14:20	I.Sh.E
	14:30	I.Tr.E
	22:34	II.Ec.D
Dec. 7	1:18	II.Oc.R
	9:30	I.Ec.D
	11:52	I.Oc.R
	20:29	III.Sh.I
	21:12	III.Tr.I
	22:24	III.Sh.E
	23:18	III.Tr.E
Dec. 8	6:38	I.Sh.I
	6:49	I.Tr.I
	8:48	I.Sh.E
	9:01	I.Tr.E
	17:42	II.Sh.I
	18:07	II.Tr.I
	20:02	II.Sh.E
	20:29	II.Tr.E
Dec. 9	3:58	I.Ec.D
	6:23	I.Oc.R
Dec. 10	1:06	I.Sh.I
	1:20	I.Tr.I
	3:17	I.Sh.E
	3:31	I.Tr.E
	11:52	II.Ec.D
	14:43	II.Oc.R
	22:27	I.Ec.D
Dec. 11	0:53	I.Oc.R
	10:44	III.Ec.D
	13:49	III.Oc.R
	19:35	I.Sh.I
	19:50	I.Tr.I
	21:45	I.Sh.E
	22:01	I.Tr.E
Dec. 12	7:00	II.Sh.I
	7:32	II.Tr.I
	9:19	II.Sh.E
	9:54	II.Tr.E
	16:55	I.Ec.D
	19:23	I.Oc.R
Dec. 13	14:03	I.Sh.I
	14:20	I.Tr.I
	16:14	I.Sh.E
	16:32	I.Tr.E
Dec. 14	1:09	II.Ec.D
	4:07	II.Oc.R
	11:24	I.Ec.D
	13:53	I.Oc.R
Dec. 15	0:27	III.Sh.I
	1:40	III.Tr.I
	2:23	III.Sh.E
	3:46	III.Tr.E
	8:31	I.Sh.I
	8:51	I.Tr.I
	10:42	I.Sh.E
	11:02	I.Tr.E
	20:17	II.Sh.I
	20:56	II.Tr.I
	22:37	II.Sh.E
	23:18	II.Tr.E
Dec. 16	5:52	I.Ec.D
	8:24	I.Oc.R
Dec. 17	3:00	I.Sh.I
	3:21	I.Tr.I
	5:11	I.Sh.E
	5:32	I.Tr.E
	14:27	II.Ec.D
	17:32	II.Oc.R
Dec. 18	0:21	I.Ec.D
	2:54	I.Oc.R
	14:42	III.Ec.D
	18:17	III.Oc.R
	21:28	I.Sh.I
	21:51	I.Tr.I
	23:39	I.Sh.E
Dec. 19	0:02	I.Tr.E
	9:35	II.Sh.I
	10:20	II.Tr.I
	11:54	II.Sh.E
	12:43	II.Tr.E
	18:49	I.Ec.D
	21:24	I.Oc.R
Dec. 20	15:57	I.Sh.I
	16:21	I.Tr.I
	18:08	I.Sh.E
	18:33	I.Tr.E
Dec. 21	3:44	II.Ec.D
	6:57	II.Oc.R
	13:18	I.Ec.D
	15:54	I.Oc.R
Dec. 22	4:25	III.Sh.I
	6:07	III.Tr.I
	6:22	III.Sh.E
	8:13	III.Tr.E
	10:25	I.Sh.I
	10:52	I.Tr.I
	12:36	I.Sh.E
	13:03	I.Tr.E
	22:52	II.Sh.I
	23:44	II.Tr.I
Dec. 23	1:11	II.Sh.E
	2:07	II.Tr.E
	7:46	I.Ec.D
	10:24	I.Oc.R
Dec. 24	4:54	I.Sh.I
	5:22	I.Tr.I
	7:04	I.Sh.E
	7:33	I.Tr.E
	17:02	II.Ec.D
	20:22	II.Oc.R
Dec. 25	2:14	I.Ec.D
	4:55	I.Oc.R
	18:39	III.Ec.D
	22:43	III.Oc.R
	23:22	I.Sh.I
	23:52	I.Tr.I
Dec. 26	1:33	I.Sh.E
	2:03	I.Tr.E
	12:09	II.Sh.I
	13:09	II.Tr.I
	14:29	II.Sh.E
	15:31	II.Tr.E
	20:43	I.Ec.D
	23:25	I.Oc.R
Dec. 27	17:51	I.Sh.I
	18:22	I.Tr.I
	20:01	I.Sh.E
	20:33	I.Tr.E
Dec. 28	6:19	II.Ec.D
	9:47	II.Oc.R
	15:11	I.Ec.D
	17:55	I.Oc.R
Dec. 29	8:24	III.Sh.I
	10:21	III.Sh.E
	10:34	III.Tr.I
	12:19	I.Sh.I
	12:40	III.Tr.E
	12:52	I.Tr.I
	14:30	I.Sh.E
	15:03	I.Tr.E
Dec. 30	1:26	II.Sh.I
	2:32	II.Tr.I
	3:46	II.Sh.E
	4:55	II.Tr.E
	9:40	I.Ec.D
	12:25	I.Oc.R
Dec. 31	6:48	I.Sh.I
	7:22	I.Tr.I
	8:58	I.Sh.E
	9:34	I.Tr.E
	19:37	II.Ec.D
	23:11	II.Oc.R

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Imbrium's Eyebrow

Is oddly shaped Mare Frigoris part of the Imbrium impact basin?

Although its name means cold, we only see **Mare Frigoris** when illuminated by sunlight and therefore quite hot. In fact, we see Frigoris so often because it stretches about 1,600 km (1,000 miles) between the crater **Atlas** near the Moon's northeastern limb and **Sinus Roris** along the northwestern limb. You can spot some part of Mare Frigoris typically every night between day 4 and 12 of each lunation. Its ease of visibility, however, is not matched by an easy understanding of why it has such an elongated shape, like an eyebrow over **Mare Imbrium**.

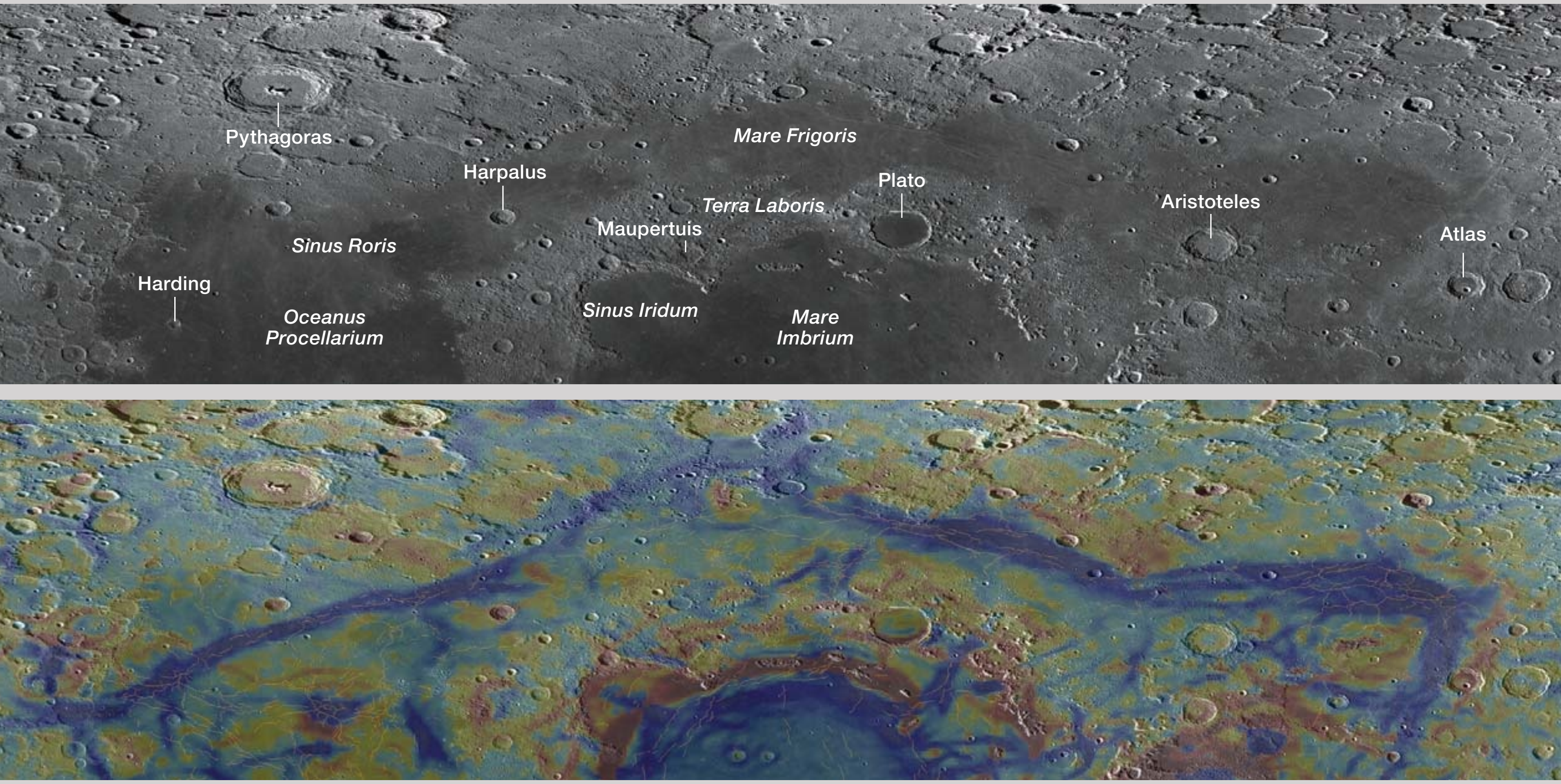
Most large maria appear to be roughly circular because they fill the circular depressions of impact basins. This is most readily seen at **Mare Crisium,** where the basin's surrounding rim is nearly continuous. Similarly, the curved **Montes Apenninus** range and its continuation along **Montes Caucasus** and the fragmentary **Montes Carpatus** clearly define half of the circular Imbrium basin that lavas filled long ago. Frigoris appears to be the odd mare out.

Not so, says lunar geologist Don Wilhelms. He suggests that Frigoris is actually *within* the Imbrium basin, because the extrapolated rim of a circle defined by the Apenninus, Caucasus, and Carpatus ranges passes along the northern shore of Mare Frigoris roughly in the same radial position to the basin's rim as Palus Putredinis, just inside the mountains' long arc. But then what formed the broad arc of rugged terrain (once called Terra Laboris by lunar mapper Michael van Langren nearly 370 years ago) between **Plato** and **Sinus Iridum** that separates Imbrium from Frigoris? One proposal was that the arc slid as a mega-landslide south, opening up Mare Frigoris. This spectacularly outrageous interpretation implies Plato and Sinus Iridum must have formed afterward — otherwise they would have been crumpled by the wholesale movement. But much of the roughness of Terra Laboris consists of ejecta from the formation of these two undeformed impact craters.

Now three recent findings provide new evidence about the origin of Mare Frigoris. First, Juha Vierinen (University of Tromsø, Norway) led a team in

▼ *Top:* Mare Frigoris arches near the Moon's northern limb and is visible throughout most of each lunation. *Bottom:* Gravitational anomalies mapped by NASA's GRAIL orbiter, combined with a map highlighting wrinkle ridges (seen as orange lines), show that both features closely parallel the northern rim of Frigoris.

NASA / GSFC / ARIZONA STATE UNIVERSITY (2)



interpreting lunar radar images from the Jicamarca Radio Observatory in Peru. Impact-fractured terrain appears bright in radar images due to multiple reflections within the jumbled rock, while coherent (solid) lava flows don't scatter radar energy as much and thus appear dark. In the Jicamarca image, Terra Laboris appears as dark as Mare Frigoris. Apparently, the radar energy's 6-meter wavelength penetrated deeply enough to detect mare material *under* the Plato and Iridum ejecta. In fact, by observing carefully near full Moon, you can see that dark mare lavas from Mare Frigoris embay some of this area.

The existence of lavas under Plato helps explain several features, including its lava-flooded floor, sinuous rilles with vents near Plato that cross rugged terrain nearby, and the rilles between Maupertuis and Plato. These volcanic manifestations were difficult to explain before the Vierinen team's findings.

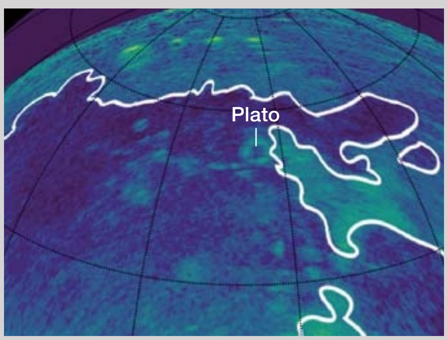
The second piece of evidence comes from a global map of mare ridges visible in Lunar Reconnaissance Orbiter Camera (LROC) images compiled by Tyler Thompson of Arizona State University and colleagues. This data set, and many others, is available in the Layers option of the recently updated LROC QuickMap (**quickmap.lroc.asu.edu**). Since many of Frigoris's ridges are parallel to the mare's northern margin, compressional forces were squeezing the crust from north and south. So Frigoris was not formed by extension — the mega-slide theory doesn't work.

The third bit of evidence comes from a map of gravitational gradients produced by the Gravity Recovery and Interior Laboratory (GRAIL) spacecraft. Jeffrey Andrews-Hanna, then at Colorado School of Mines, and many colleagues unexpectedly discovered a series of long, narrow gravity anomalies — I call them "worms" — that border a region of the lunar nearside that has high concentrations of radioactive elements and contains most maria. One of the best-defined worms parallels the northern shore of Mare Frigoris from Atlas in the east all the way to **Harding**, considerably west of the official boundary of Frigoris. (These GRAIL data are also available on QuickMap and can be overlain over imagery that highlights the wrinkle ridges, as seen on the bottom of the facing page.)

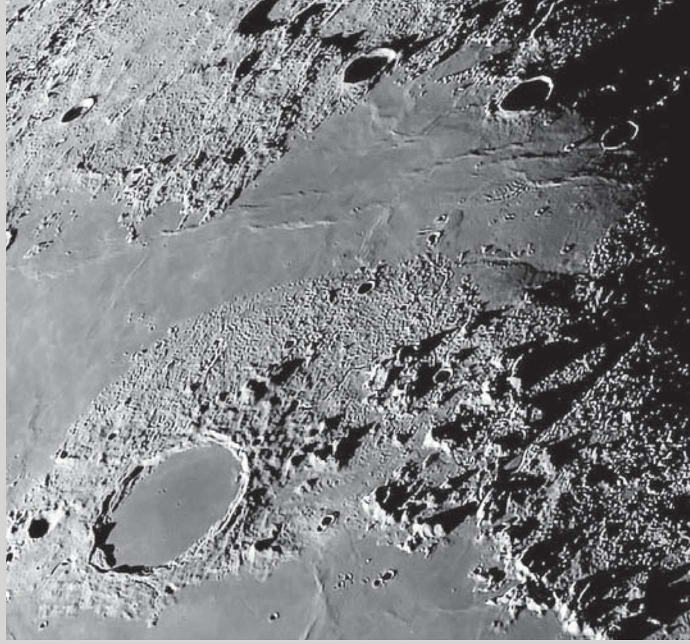
Andrews-Hanna and his team noticed that nearly all of the ridges that parallel the northern shore of Frigoris coincide with the worms. They interpret the worms as subsurface rifts and dikes that once fed magma to the surface and are now filled with dense, solidified lava. If so, Mare Frigoris exists because of the underlying worms, the byproduct of high heat concentrations, which still has no good explanation.

So what does this new information tell us about Mare Frigoris? The radar data show that Terra Laboris and surrounding crater ejecta sits atop mare lava. Does this mean that the Frigoris flows are more widespread than we thought? Lavas in this area from Imbrium and Frigoris are compositionally identical (iron-rich, titanium-poor) basalts of similar age (3.4 billion years). And the surface of Mare Imbrium slopes downward to the north. So the Terra Laboris lavas could have flowed in from either mare or might have erupted from their own vents.

The western end of Mare Frigoris is generally considered to be near **Harpalus**



▲This deep-penetrating radar image shows mare lava as blue. The area west of the crater Plato (appearing as the greenish oval), previously known as Terra Laboris, is nearly invisible, implying mare lavas underlie the bright material we see at the telescope.



▲Wrinkle ridges running parallel to the northern border of Mare Frigoris are seen in this image captured shortly following the third quarter phase.

crater at about 45° W longitude. However, the continuation of the Frigoris worm and its overlying mare ridges to about 75° W encourages the speculation that Mare Frigoris, as defined by the lava sources that formed it, actually extends that far to the west. If so, Sinus Roris is simply a patch of darker, high-titanium lava that is part of Mare Frigoris, whereas Frigoris and the suggested western extension are all lighter, low-titanium mare lavas. This means that the northern limit of Oceanus Procellarum is near the crater **Rümker**. Indeed, the lavas just east of Rümker are rich in titanium and are less than 2 billion years old, like many of the Oceanus Procellarum flows farther south.

Frigoris is often the forgotten mare because it lacks the concentric fractures, sinuous rilles, and magnificent craters common to other major maria. But next time you observe it, look for the subtle wrinkle ridges that mark its buried worms, and the suggested extensions under Terra Laboris and west of Sinus Roris.

■ Contributing Editor **CHUCK WOOD** now has an asteroid to worry about: 363115 Chuckwood (formerly 2001 FW224) is a 16th-magnitude dark and icy mountain cruising around the Sun at an average distance of 3.1 a.u.

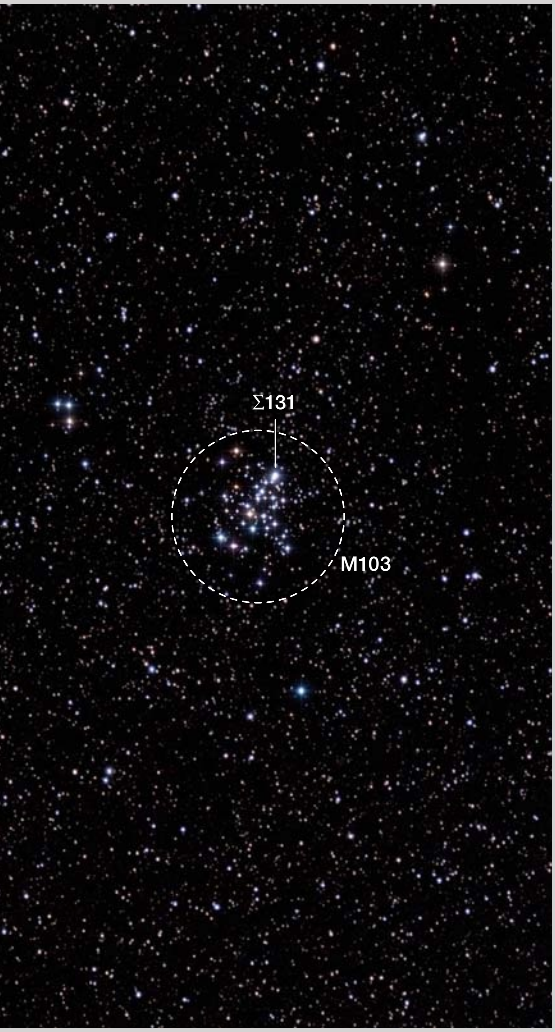
LUNAR IMAGE: ROBERT REEVES;
RADAR: J. VIERINEN / UNIVERSITY OF TROMSØ / JRO

FIND YOUR CLUB: skyandtelescope.com/astronomy-clubs-organizations.

The Frosty Sky

Bundle up and go out into the cold. Your queen awaits.

The stars are glittering in the frosty sky,
Frequent as pebbles on a broad sea-coast;
And o'er the vault the cloud-like galaxy
Has marshalled its innumerable host.
— Charles Heavysege, Sonnet XIV, 1865



▲ M103 is a modest smudge of light northeast of Delta Cassiopeiae. Look for the 7.3-magnitude primary of double star STF 131 in the northwest region of the cluster.

DOUG GERMAN

December nights fall crisp and cold at mid-northern latitudes, when even the Milky Way seems like a wreath of frost condensed along some join in the vault of the sky. One of the constellations softly silvered by its light is Cassiopeia, the Queen; high in the northern sky we now see her brightest gems forming an M for Her Majesty.

Alpha (α) Cassiopeiae is officially the constellation's brightest star at magnitude 2.24, although nearby Gamma (γ) Cas is an eruptive, irregular variable star that sometimes outshines it. Alpha is an orange giant star, 42 times the Sun's diameter, sitting about 228 light-years away from us. This star is commonly known as Shedar, derived from an Arabic word meaning "the breast" and denoting its position in the traditional constellation figure, which portrays our celestial Queen sitting with her head to the west.

In 1780 William Herschel discovered a fainter star 53″ northwest of Alpha. He described the pair as extremely unequal with colors of pale red for the bright star and "dusky" for its companion. These stars are even more widely separated now, and through my 130-mm refractor at 37×, I see the primary as deep yellow and the 8.8-magnitude attendant, roosting west-northwest, as yellow-orange. A study of the relative motion of the components proves this is merely an optical double rather than a genuine binary.

Between Delta (δ) and Epsilon (ε) Cassiopeiae rests a queenly quartet of open clusters whose most visited member is **Messier 103**, discovered by Charles Messier's colleague Pierre Méchain with a 3-inch refractor in 1781. Despite its modest appearance, M103 is a true cluster, but the number of probable members differs wildly from source to source depending on the criteria applied. Modern values range from 77 to 526 stars.

M103 offers fewer stars to the backyard telescope but is a pretty group nonetheless. The 130-mm scope at 37× reveals a 5′ triangle of 13 bright to faint stars. The three most prominent sparks lie along the northeastern side of the triangle, with the brightest one at the triangle's pointy end. This is the double star **Struve 131** (STF 131 or Σ131), whose companion is easily visible 13.9″ to the southeast. At 117× I tally 23 stars dotting the triangle, plus several stars sprinkled outside the triangle's long sides. The middle star of the trio that defines the triangle's northeastern side smolders deep orange. My 15-inch reflector at 216× teases out 40 to 45 stars within roughly 6′.

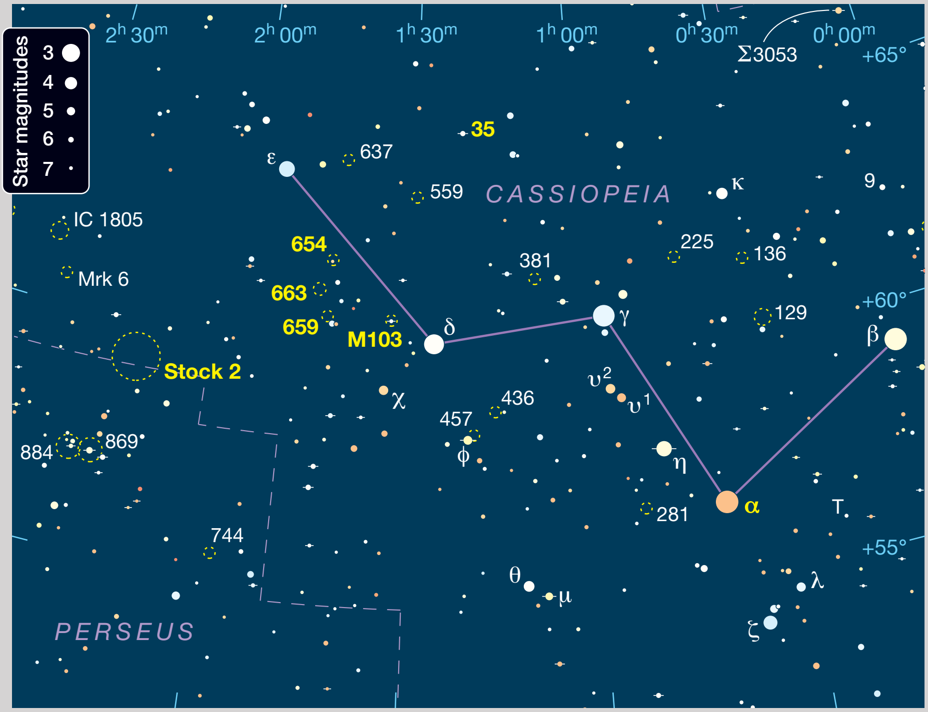
If I place M103 in the west-southwestern edge of the refractor's 37× field of view, the wide-angle eyepiece lets me cram **NGC 663** into the scene as well. It's a beautiful group of 25 fairly bright to very faint stars, its core dusted with the powdery light of unresolved suns. Centering NGC 663 draws the last two members of the open cluster quartet into view, **NGC 654** and **NGC 659**, both much smaller than their neighbor. The former is a bright mist stippled with a splash of diamond-dust stars. A few slightly more conspicuous jewels decorate the fringes, and a golden, 7th-magnitude star burnishes its southeastern edge. NGC 659 is simply a knot of five faint stars with perhaps a feathering of fine fog.

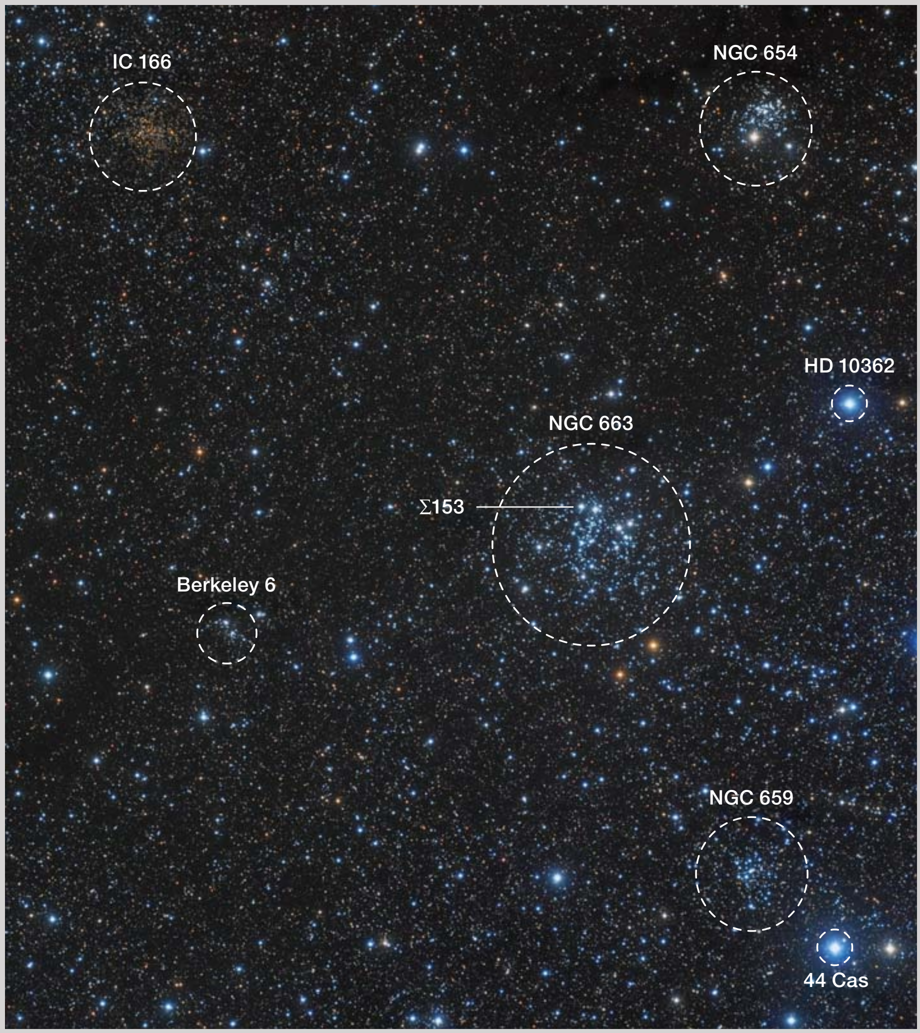
At 102× NGC 663 sports about 50 stars, magnitude 8.5 and fainter. The cluster's densely starred core spans 8½′, while the sparse, irregular halo swells the group to 13′. The cluster's lucida (brightest star) glistens in the north-northeastern portion of the core. Despite its *B2II* spectral type, which identifies it as a blue-white bright giant, the star looks yellow-white. Its light is significantly filtered by intervening dust in the plane of the Milky Way, lending the star the yellower cast indicated by its color index of +0.65. Such a hue is equivalent to an unfiltered G1V star, much like our Sun. **Struve 153** gleams 1.3′ east of the lucida. This noteworthy pair presents a 9th-magnitude primary harboring a 10th-magnitude companion 7.7″ to the east-northeast.

Also perused at 102×, NGC 654 discloses 15 stars, excluding the bright one at its edge, with the most crowded region north of the cluster's center. NGC 659 seems less obvious at this magnification, showing nine stars magnitude 10.5 and fainter, loosely scattered across an east-west band covering 3½′ × 1½′. Boosting the power to 164× gives a score of stars to NGC 654 and a dozen to NGC 659.

NGC 663 is even more appealing in my 10-inch reflector at 88×. At least 60 stars spangle a patch of sky about ¼° across, the four brightest shining in shades of yellow. A cradle of stars cups the cluster from the south; its brightest star (SAO 11958) is deeply red-orange. A somewhat dimmer star 4.2′ southeast shares the same hue. Adding more color to the tableau, the bright star off the cluster's west-northwestern side glows deep orange. NGC 654 bares 34 stars within 5¼′, while NGC 659 has 21 stars straggling across a 4¼′ × 1¾′ band, plus a few outliers to the south.

The members of our foursome are youthful open clusters, their ages ranging from about 14 million years for NGC 654 to 35 million years for NGC





▶ It's a short hop from M103 to the bright sparks of NGC 663. You can spend nights studying just this part of the sky, with its rich starfield, several open clusters, and abundance of dark nebulae.

JIM THOMMES

◀ If you want to conquer the Muscle Man, pick up a pair of binoculars. Stock 2 covers a sprawling 60 arcminutes, so use the widest field of view to help you win the challenge.

DAN CROWSON

659. They also dwell in the same region of space, roughly 6,000 to 7,000 light-years away from us.

Another fetching optical double star sits north of Delta in the guise of **35 Cassiopeiae**. Through my 130-mm scope at 23×, this nicely contrasting pair shows a pale-yellow-white, 6.3-magnitude primary guarding a reddish-orange, 8.6-magnitude companion 57″ to the north-northwest.

Our final stop is the open cluster **Stock 2**, reclining on the Cassiopeia-Perseus border, 4° east-southeast of NGC 663. Only 990 light-years away from us, Stock 2 is much closer than our quartet. It's also considerably older at 170 million years.

Deep-Sky Sights in Cassiopeia

Object	Type	Mag(v)	Size/Sep	RA	Dec.
α Cas	Double star	2.2, 8.8	70″	$0^h\ 40.5^m$	+56° 32′
M103	Open cluster	7.4	6.0′	$1^h\ 33.4^m$	+60° 40′
Σ131	Double star	7.3, 9.9	13.9″	$1^h\ 33.2^m$	+60° 41′
NGC 663	Open cluster	7.1	15′	$1^h\ 46.3^m$	+61° 13′
NGC 654	Open cluster	6.5	6.0′	$1^h\ 44.0^m$	+61° 53′
NGC 659	Open cluster	7.9	6.0′	$1^h\ 44.4^m$	+60° 40′
Σ153	Double star	9.4, 10.4	7.7″	$1^h\ 46.6^m$	+61° 16′
35 Cas	Double star	6.3, 8.6	57″	$1^h\ 21.1^m$	+64° 39′
Stock 2	Open cluster	4.4	60′	$2^h\ 14.7^m$	+59° 29′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Covering a full degree of sky, Stock 2 is best appreciated through a telescope offering a large field of view. Seen through a wide-angle eyepiece that gives the 130-mm refractor a true field of 2.7° and a magnification of 23×, the cluster boasts 75 stars and is framed by a generous halo of background sky that helps it stand out from its surroundings. A striking pair of 7th-magnitude, yellow-white and yellow-orange stars watches over the cluster from the northeast.

Stock 2 encompasses the head, arms, and torso of an asterism known as the Muscle Man, which sprang from the inventive imagination of Massachusetts amateur John Davis. The Muscle Man can be discerned through the 130-mm refractor, but the scope shows so many stars that the Muscle Man is nearly lost in a cloud of tiny midges. Following the unkindly stereotype of a guy that's all brawn and no brains, our Muscle Man has a tiny pin-head, which you'll see on the cluster's western side. The Muscle Man's arms are curved up and in toward his head as though flexing his muscles. The star marking his northern hand is yellow, and the southern hand burns yellow-orange. The Muscle Man's extended legs stick mostly outside the cluster, toward the east. His southern foot glows orange, and the next star up that leg shines yellow-orange. Four stars near the end of his northern leg cast light in shades of yellow-orange to red-orange.

The Muscle Man is more clearly perceived through binoculars, which highlight the brighter stars of the asterism by subduing the many dim stars of Stock 2. Our strongman clasps a bright leash of stars that leads us to the beautiful Double Cluster in Perseus, a great stop on any night and one of the featured sights in next month's column. See you then!

■ On a cold winter's night, you'll find Contributing Editor **SUE FRENCH** keeping warm near her telescopes.

New S&T Tours in 2019!

African Stargazing Safari
July 29–August 4, 2019

Join astronomer Stephen James O'Meara in wildlife-rich Botswana for evening stargazing and daytime safari drives at three luxury field camps. Only 16 spaces available! Optional extension to Victoria Falls.

skyandtelescope.com/botswana2019

Iceland Auroras
September 29–October 2, 2019

This is our 6th year running this popular tour of Iceland. Visit historic sites, geysers, and towering waterfalls with a guide; at night, seek the fabled northern lights. Fine restaurants and hotels await you.

skyandtelescope.com/iceland2019

Australia Observatories
October 1–8, 2019

Travel Down Under to tour top observatories, including Siding Spring and "The Dish" at Parkes. Go wine-tasting, hike in nature reserves, and explore eclectic Sydney. Options to Great Barrier Reef and Uluru.

skyandtelescope.com/australia2019

See all *S&T* tours at skyandtelescope.com/astronomy-travel

Remote Imaging with Chilescope

We test an online telescope service with a focus on planetary photography.

Chilescope Astronomy on Demand

U.S. Price: $1 per point ($200/hour for the 1-meter telescope), with discounts for deep-sky imaging depending on the lunar phase

chilescope.com

What We Like

Operating a 1-meter telescope

Same controls as imaging at home

Reschedule due to poor seeing at no additional cost

What We Don't Like

Predicting seeing conditions

Raw videos not provided

Chilescope founders Sergey Pogrebisskiy (at left) and Ivan Rubtzov in front of the four Chilescope domes in the Andes mountians, Chile.

DAMIAN PEACH / CHILESCOPE

WHAT AMATEUR ASTRONOMER hasn't fantasized about operating a large telescope in an extremely dark location that regularly experiences good seeing conditions? While many of us may have had glimpses through large instruments at star parties or at observatory public nights, being able to image through one has been mostly a dream . . . until now.

Operating telescopes remotely isn't new. There are several established telescope-hosting facilities at premium sites in Africa, North America, South America, and Australia, where individuals with the means can lease a spot at a "telescope farm" for their equipment and image remotely. Some facilities also have scopes that users can rent to take dazzling deep-sky photos or perform extended research. But one type of astrophotography has remained impractical for imagers, until now: planetary imaging.

Chilescope

A group of intrepid Russian astronomers has taken the idea of remote imaging a big leap forward by providing everything needed to shoot deep-sky objects and the planets with world-class instruments from the often-steady skies in South America. Chilescope was founded by partners Ivan Rubtzov and Sergey Pogrebissky, with the support of astronomer Yuri Beletsky of the Carnegie Institution for Science. The remote observatory is located in the Chilean Andes at west longitude 70° 45' and south latitude 30° 27', at an elevation of 1,560 meters (5,118 feet). It's a site that often experiences sub-arcsecond seeing, which is ideal for high-resolution astrophotography with large apertures.

The observatory hosts three telescopes available for rent by the hour, including a pair of 20-inch (50-cm) Astrosysteme Austria (ASA) f/3.8 Newtonian astrographs, each riding atop ASA DDM85 direct-drive equatorial mounts and housed in individual 4-meter domes. Both scopes are equipped with Finger Lakes Instrumentation ProLine PL16803 CCD cameras and filter wheels loaded with 50-mm square L, R, G, B, Hα, S II, and O III filters.

The premier instrument of the facility, however (and the one that certainly caught my attention), is a truss-tube 1-meter f/8 ASA Ritchey-Chrétien with dual-Nasmyth focuses designed by renowned optical engineer Philipp Keller and manufactured by LOMO. The scope resides in a 5.5-meter dome and is borne by a massive direct-drive alt-azimuth mount, also manufactured by ASA.

On one side of the fork mount is the deep-sky imaging train consisting of another FLI PL16803 camera with a fully stocked filter wheel and a dedicated f/6.8 reducer/corrector, providing an 18.2-arc-minute-square field of view. The other Nasmyth focus features a dedicated tele extender that produces a focal ratio of f/16. Through it, a ZWO ASI174MM high-speed planetary video camera is available to image the Moon and planets at an image scale of 0.07 arcseconds per pixel. Planetary imagers can record their targets through an assortment of planetary filters including L, R, G, B, UV, and three bands of near-infrared wavelengths (IR 642, IR 685, and IR 742). Additional filters are expected to come online in the near future, including methane (CH_4) and IR 1,000.

Due to the remote location of Chilescope, power is provided by a hybrid solar and diesel generator with 70 solar panels on the property, with diesel fuel only being necessary when the Sun isn't visible for a day or more, or in the event of a total power disruption. Internet is provided via a radio relay with speeds as high as 30 megabytes per second.

Remote Operation

Deep-sky imaging with Chilescope operates like most other remote facilities. Users set up an account and purchase points at US $1 each, which can then be spent on telescope time. Once an account is established, you select the instrument you intend to use and open a scheduler, which shows what time periods are open for purchase. Time on the 20-inch astrographs costs 60 points per hour, with a minimum purchase of 1 hour. There are discounted rates for deep-sky imaging based on the phase of the Moon. For example, while the period around New Moon is 60 points per hour, a 35% discount is offered when booking time during waning or waxing crescent phases, and this increases to a 75% discount as the Moon grows full. Additionally, there are cumulative discount rates for large block purchases of telescope time for both planetary and deep-sky imaging.

A video tutorial and PDF guides are available on the Chilescope website to help you familiarize yourself with operations of the facilities for deep-sky and planetary imaging, and I strongly encourage you to go over them before starting out.

Imagers using the facilities for deep-sky imaging should plan out their observing session thoroughly using the planetarium software of their choice that includes camera field-of-view indicators. This avoids wasting valuable time on framing your subjects, determining what filters to image with, and so forth.

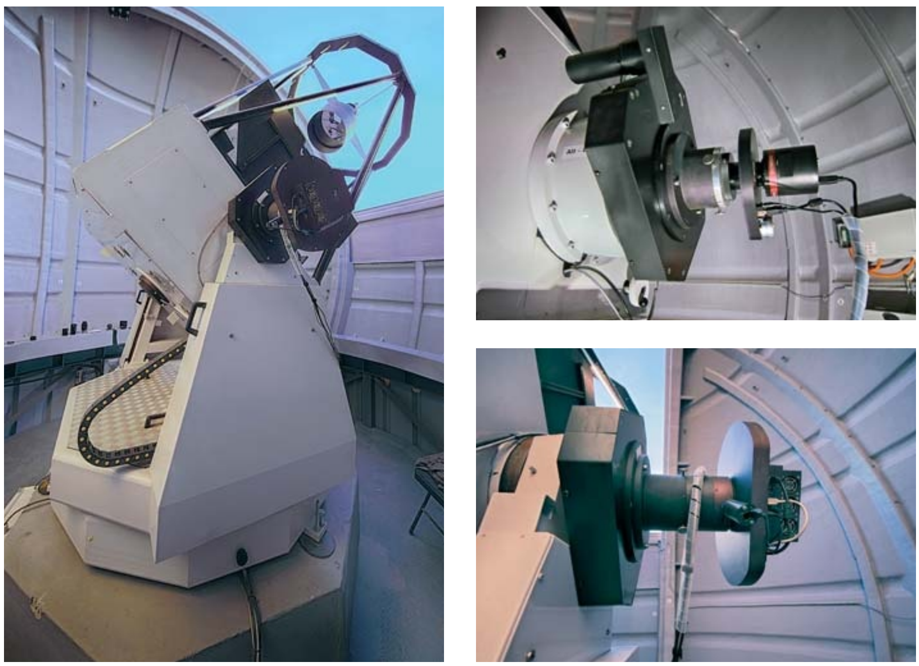
▶ The spiral galaxy M104 displays intricate small-scale detail in this 4-hour cumulative exposure captured through the 1-meter Chilescope.

You also need to make sure your targets are at least 30° above the horizon at the start or before the end of the observing time you book. All Chilescope telescopes are limited to observing objects that are at least 30° up. Also, the scopes will not allow you to book imaging time when the Sun is less than 15° below the horizon.

The telescopes are operated for deep-sky imaging using an online form where you input your target coordinates, the camera rotation, the filters and exposure times, autofocusing routine, and autoguiding parameters. Once your session is created, it will execute automatically at the designated time. You'll receive an email with the session status and a link to log on in real time if you desire. After your data are ready, an email with a link to your files, as well as any neccessary calibration frames, is provided for download.

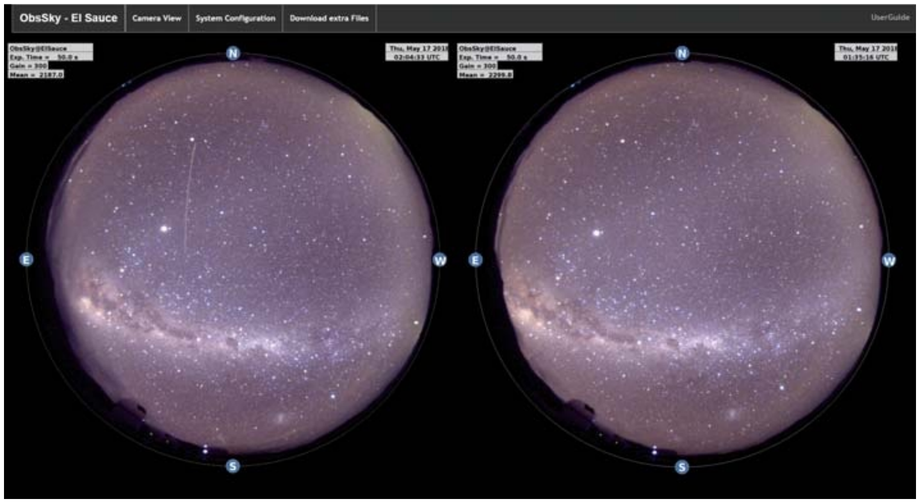
Although I didn't use the facilities for deep-sky imaging, rates as low as US $15 per hour during full Moon are a great value: While you won't be able to do much broadband LRGB imaging during full Moon, narrowband imaging, particularly through a hydrogen-alpha filter, is very appealing. Also, small, bright targets such as planetary nebulae

▼ The premier instrument at Chilescope is a 1-meter f/8 Ritchey-Chrétien reflector with dual-Nasmyth focus on each side of its massive alt-azimuth mount. One side hosts a ZW Optical ASI174MM-Cool high-speed CMOS camera for imaging the Moon and planets (below right), while the other uses an FLI PL16803 CCD camera for deep-sky clients (bottom right).



M104: CHILESCOPE.COM; TELESCOPE AND CAMERAS: DAMIAN PEACH / CHILESCOPE (3) are relatively impervious to moonlight, particularly when they are far away from the Moon in the sky.

Chilescope provides a link to weather sites to help users determine seeing and transparency conditions, and a color all-sky camera lets you monitor the local conditions in real time.



▲ Users can monitor the local sky conditions using an all-sky camera while observing with any of the Chilescope telescopes.

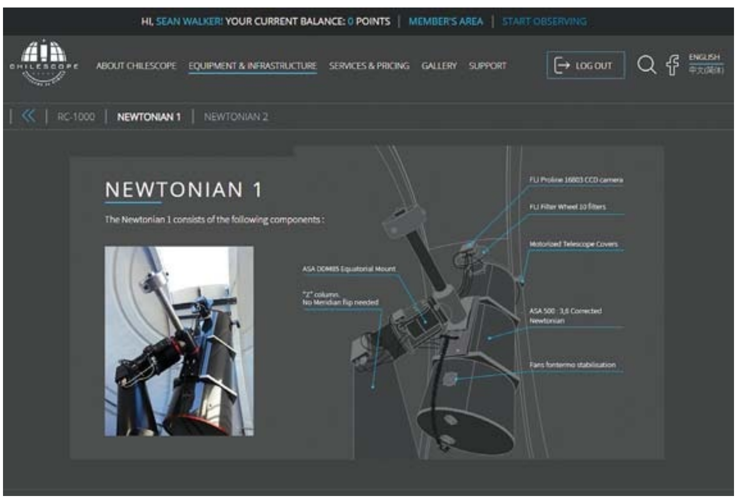
Remote Planets

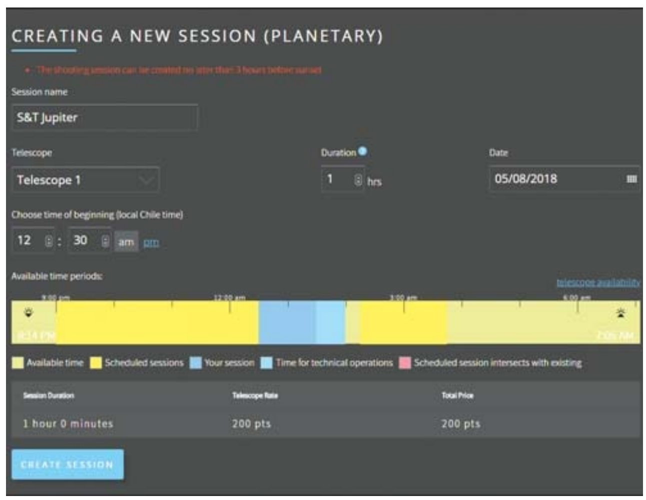
My interest in Chilescope primarily concerned the planets. Although I shoot all kinds of astrophotography including deep-sky and the occasional nightscape, I'm a solar system aficionado at heart, particularly when Mars is nearing opposition. That said, this year, and for several years going forward, the bright outer planets Mars, Jupiter, and Saturn are slowly traversing the southern extent of the ecliptic. From my northerly home, none of these exciting targets gets much more than 25° above the horizon, so my opportunities for sharp, high-resolution planetary imaging are extremely limited, as they are for many European and North American amateurs.

Enter Chilescope. The ability to use a 1-meter telescope for remote planetary imaging is a first that I'm aware of. Remote imaging of the planets is difficult for several reasons, the first being that the pointing accuracy of commercial telescope mounts, while excellent, was previously not quite up to the task of landing a target on a planetary camera's small detector at 16,000 mm focal length. Add to this other variables such as instrument flexure and precise collimation of a mirror-based telescope system at an unattended facility, and the technological challenges of remote planetary imaging become daunting to say the least.

Chilescope takes care of these problems by using a professional observatory-class instrument and by having an operator online to help with pointing the scope at the customer's chosen targets as well as offering some imaging assistance. These tasks are often handled by the fourth Chilescope partner: planetary photographer Damian Peach. Peach helps clients with planetary imaging runs to ensure users get the most out of their time.

I used the 1-meter scope on several nights from April through June this year. A typical imaging run looks virtually the same as my experience imaging from my own backyard, with two differences — I wasn't outside with my scope, and I couldn't simply swing over to another target without assistance.

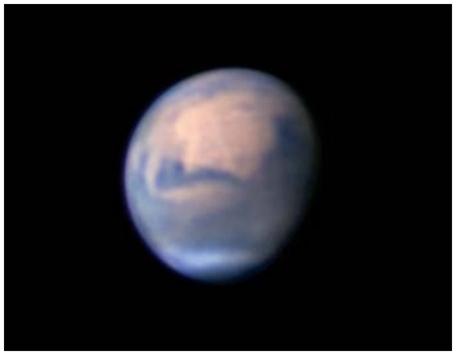




▲ *Left:* Two computer-controlled 20-inch ASA astrographs equipped with FLI ProLine PL16803 CCD cameras and a full assortment of filters are available for deep-sky imaging rental under the pristine skies of the Chilean Andes. *Right:* Booking time for either deep-sky or planetary imaging requires selecting a designated time slot. Users are encouraged to book their observations well in advance, because the time slots when the planets are best placed each night fill up quickly.

ALL-SKY CAMERA SHOTS: CHILESCOPE

▶ The author's best color images of Mars and Saturn, both captured on the morning of April 28 using the 1-meter telescope. Mars was 10.8 arcseconds across at the time.



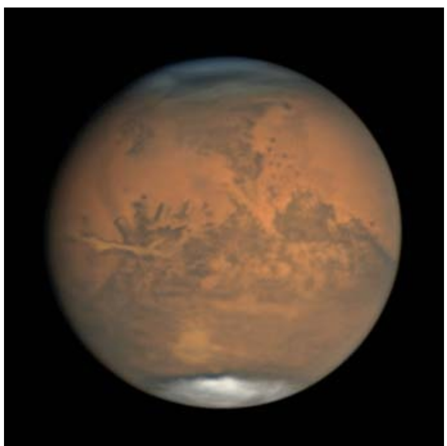
Other than that, using the 1-meter was much like imaging at home, except that I log onto the telescope control computer using the software *Teamviewer* (**teamviewer.com**), which is available for free for individual (non-commercial) users. This program allows you to log onto another computer and take control of it, running software programs on it as if you are physically present. The software works quite well, and the few times I lost my connection, I was able to log back on within seconds.

Booking time for planetary imaging on the 1-meter is the same as deep-sky imaging, except you must operate the scope in real time. Once on the control computer, the camera is operated using *FireCapture* (**firecapture.de**), a popular freeware camera-control program designed specifically for planetary imaging with PC's. Most planetary imagers are familiar with the program, though the important controls for using with the 1-meter are detailed in the PDF tutorial.

Perhaps the biggest challenge I had (besides trying to book a session with good seeing conditions) was focusing the telescope from 10,000 miles away. This is where a good high-speed internet connection is crucial. I use cable internet, and the live framerate of between 5 and 10 frames per second was adequate to ensure precise focus. When I experienced some signal lag, switching the View setting at the top of the *Teamviewer* screen to "Optimize quality" ensured that signal compression didn't compromise the appearance of the planet. I spent about 10 minutes focusing each filter before starting my imaging runs. Once you focus for a particular filter, the control software recalls the focus position, so you don't have to focus again during your scheduled run.

I chose to concentrate on Mars, Saturn, and Jupiter as each planet was near or approaching opposition, though spotty weather during my several attempts to shoot Jupiter resulted in several aborted attempts. And while I never experienced truly great seeing, I was able to come away with some fine portraits of both Mars and Saturn that easily beat my best results taken from home with my much smaller 12½-inch Newtonian reflector.

Shooting went well, but it wasn't without some problems, though most were beyond the control of Chilescope. One night while anxiously awaiting my scheduled time, I watched the all-sky camera display a gorgeous clear night, only to have clouds *form* over the site as I was focusing on my target! Another night while fighting to achieve focus in marginal conditions, the scope suddenly slewed off target and shut down due to a conflict with the deep-sky imaging control program, which has since been rectified.



This exquisitely detailed view of Mars was captured by Chilescope partner Damian Peach using the 1-meter telescope under very good conditions on August 9. It shows the potential of the instrument when atmospheric conditions permit.

After my imaging session was complete, the attending operator sent a link to log onto another computer used to process the recorded videos, freeing up the control computer for the next booked session. Here I was able to stack each of my red-, green-, blue-, and infrared-filtered videos using either *Autostakkert! 3* or *RegiStax 6* into "raw" TIF or PNG files that could then be quickly downloaded. While these went well, I personally prefer having the raw videos on hand myself for future examination; the live framerate I experienced operating Chilescope was adequate for recording images, but you don't see every frame recorded in the live feed, which means that short-duration events such as asteroid strikes on Jupiter could potentially be overlooked. Perhaps Chilescope could add an option to purchase your videos on DVD.

Operating Chilescope was an exciting adventure in imaging the planets without the need of a large investment in your own telescope, mount, camera, or software, not to mention having to set up the scope or break it down each night. And while I never experienced excellent seeing with Chilescope, the system produces fantastic results in even fair seeing conditions. I highly recommend the experience, particularly while Jupiter, Saturn, and Mars are slowly traversing the lowest extent of the ecliptic during the next few years.

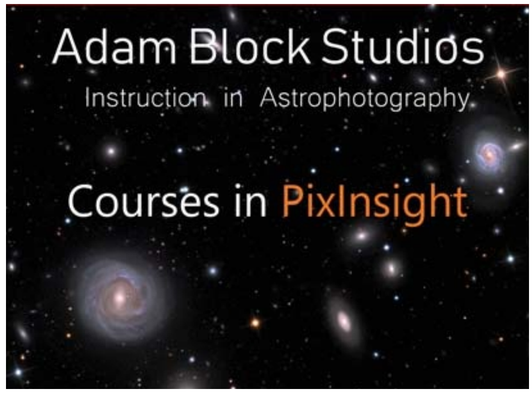
■ Associate Editor **SEAN WALKER** engages in several imaging projects, including an extended remote sky-survey partnership at **mdwskysurvey.org**.

MARS AND SATURN: SEAN WALKER / *S&T*; MARS: DAMIAN PEACH / CHILESCOPE

▶ PROCESSING LESSONS

Adam Block Studios now offers streaming video tutorials that teach astrophotographers how to use the popular image-processing software *PixInsight* via comprehensive and in-depth lessons. PixInsight Fundamentals ($180) is an in-depth primer of the core functionality of the powerful software package, while PixInsight Horizons ($250) discusses many advanced techniques to help you get the most out of your image data. The lessons are divided into clearly labeled sections that can be viewed sequentially or on demand, all delivered in Block's signature conversational style. Purchasers of either video collection are given access to more than 30 hours of content, as well as any future additions to each series at no additional cost.

Adam Block Studios
adamblockstudios.com



▲ 8-INCH ASTROGRAPH

Celestron announces the newest addition to its line of ultra-fast astrographs. The 8-inch Rowe-Ackermann Schmidt Astrograph ($1,699) is an f/2 optic designed exclusively for deep-sky imaging. The unit's 203-mm aperture and short 400-mm focal length produces a usable field of 32 mm with an off-axis illumination of 93% at 11 mm, accommodating cameras with up to APS-C format detectors, and is corrected to perform over a spectral range of 390 to 800 nanometers. The 8-inch RASA features a new focuser system with two sets of precision bearings designed to mitigate lateral movement of the primary mirror when slewing, focusing, or tracking the sky. The OTA is 24.7 inches long, weighs just 17 lbs, and includes a built-in cooling fan and a CGE dovetail mounting bar. An M42 camera adapter, C-thread camera adapter, and fan battery pack are included with purchase.

Celestron
2835 Columbia St.,
Torrance, CA 90503
310-328-9560; celestron.com

▼ LIVE VIEW CAMERA

MallinCam unveils its newest addition to the SkyRaider Video Camera series. The SkyRaider DS10c ($929.99) is built around hand-selected Sony IMX294 back-illuminated color CMOS industrial sensors with 4.63-micron-square pixels in a 10.7-megapixel array measuring 21.8 mm diagonally. The camera uses 4 gigabits DDR internal memory and can be operated in either 8- or 12-bit mode with several binning options. Its 2.65-inch-diameter cylindrical aluminum housing is designed specifically for use in HyperStar and RASA optical systems, and it connects to most telescopes with an included T-adapter or 2-inch nosepiece. The DS10c connects to your PC via a USB 3.0 interface and can output single FITS, JPEG, BMP, or PNG files, or AVI and SER video formats. The unit can also operate as an autoguider that connects to your mount via an RJ-11 port. A 5-meter (15-foot) USB 3.0 cable, guiding cable, and operating software are also included with purchase.

MallinCam
mallincam.net

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope *assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.com. Not all announcements can be listed.*

Getting the Best from Your Backyard

Imaging from a suburban backyard can be rewarding, even under light-polluted skies.

As an astrophotographer, I long to image faint targets in the night sky. The problem, though, is that I live under skies awash with skyglow, as many of us do. And while I enjoy taking road trips to dark skies in an effort to image under better conditions, nothing quite beats the convenience and comfort of imaging from my own backyard. Despite being barely able to discern the Milky Way on most clear nights, I've still been able to take many colorful, detailed images of galaxies, nebulae, and star clusters from my suburban home. Here are some of the ways I've found to mitigate the effects of light pollution — common-sense steps that might help you get the most out of your own location.

Shoot High

My backyard in Ocean Springs, Mississippi, is only a few miles from the bright lights of the city of Biloxi along the Gulf Coast. I got interested in astronomy and astrophotography long after setting family roots in the area, so I decided to make the best of what I had.

When I started imaging, I began by setting up my scope in the darkest spot in my backyard, hoping that this simple step would permit me to take good pictures. Unfortunately, my first images displayed ugly color casts, were dim and noisy, and weren't nearly as nice as what I saw others post online. So this was the first lesson I learned to improve my astrophotography: Avoid light domes.

"Light domes" are just that — large glows along the horizon from urban areas that illuminate the sky, often where interesting targets reside. One way to avoid light domes is to

GOING DEEP Shooting deep-sky objects from suburban locations is challenging, but the rewards speak for themselves. This deep, colorful image of IC 348 surrounding the bright star Omicron (ο) Persei was captured from the author's backyard observatory using a Stellarvue SV70T refractor and a QSI 583wsg CCD camera with color and hydrogen-alpha filters. Unless otherwise noted, all images were taken by the author.

simply avoid shooting objects when they are low in the sky. This can mean waiting until your chosen target reaches the meridian (the imaginary line that crosses the zenith from north to south), where it should be best placed to shoot anyway. Some areas of my sky will always be off-limits for imaging, but I can just save the targets in those areas for the times I travel to a star party or other dark-sky site.

As a general rule, I tend to avoid shooting nebulae or galaxies until they get higher than about 40° above the horizon, where the light domes aren't as bad. Some parts of my sky are worse than others, particularly toward Biloxi in the west.

This 40° rule of thumb also helps improve the signal of my images by reducing the effects of *atmospheric extinction*. The lower your target is, the more atmosphere its light must pass through before hitting your sensor, which can be described as airmass = 1 / cos (ZA), where ZA is the zenith angle (angle from zenith to your object). This is an issue because our atmosphere absorbs and scatters light, making targets fainter the closer they are to the horizon. At an elevation of 30° you are looking through twice as much atmosphere than when looking toward the zenith. Additionally, the atmosphere scatters blue light more than it does wavelengths at the red end of the spectrum, meaning that less blue light reaches your scope when your target is low. I take advantage of this by reserving my blue- and green-filtered exposures until my target is highest in the sky, and shoot red exposures when they are nearer to my 40° altitude limit.

Local Light Pollution

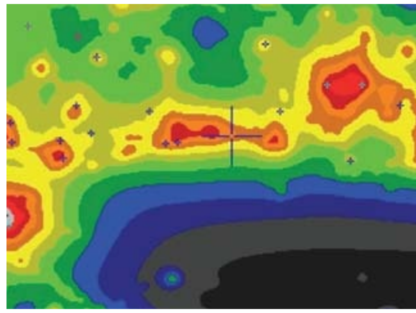
While shooting high in the sky helped improve my pictures, they still suffered from the effects of light pollution. Because of this I needed to understand how *local* light pollution was affecting my deep-sky images. Specifically, just because my scope wasn't aimed directly at a nearby streetlight didn't mean its light wouldn't affect my images. Light tends to find its way into my scope, so I had to find a better way to keep local ambient lights — streetlights, passing cars, and the neighbor's motion-activated security lights — from spoiling my images.

The best solution to local light trespass was to build a permanent home for my telescope — a backyard observatory.

My first observatory was a simple roll-off-roof design. This helped block most stray light from finding its way into my telescope and immediately made a difference in my astrophotography. Light-pollution gradients in my images became less obvious, and I began to see the limits of my other equipment.

Eventually, I decided that my local conditions warranted a more specialized solution to the problem of stray light. So after a decade, I replaced my little roll-off enclosure with an 8-foot dome from Explora-Dome (**explora-dome.com**). A dome only lets in a small section of the sky and thus blocks out anything else. It certainly solved the majority of my neighborhood's security-light problem. But being in a dome takes a little getting used to, because you don't see the entire sky at once.

If you can't build a permanent home for your equipment, there are inexpensive portable observatories that will shield your imaging rig from ambient light. Places to look for one are **365astronomy.com** and Kendrick Astro Instruments (**kendrickastro.com**).



▲ **BRIGHT SKIES** Light pollution surrounding the author's home in Ocean Springs, Mississippi, is relatively severe. This map scales light pollution as most severe in the red zones.

LIGHT POLLUTION MAP: LIGHTPOLLUTIONMAP.INFO

Camera Choice

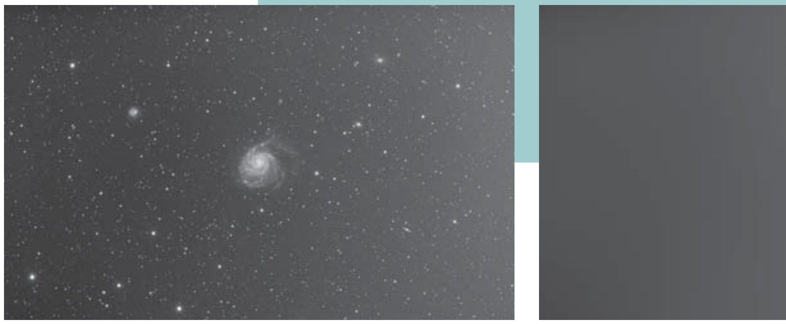
Once I was getting better data, I noticed how hard it was to get rid of gradients in images taken with a color camera. While today's color cameras are much better than when I started digital imaging almost 20 years ago, a monochrome camera wins out under bright skies, in my opinion. I find it's much easier to remove light-pollution gradients on individual monochrome, color-filtered images — as opposed to those from a one-shot-color camera. I'm able to isolate and remove light-pollution gradients in each color channel before combining them into the final image during post-processing. Additionally, a monochrome camera with a filter wheel allows you to image at full resolution through narrowband filters, which work extremely well to block many sources of light pollution.

That's not to say color cameras don't work. With the addition of a clip-in light-pollution filter, DSLR cameras can take nice deep-sky images under urban skies. These filters are available from Astronomik Filters (**astronomik.com**) and other retailers for either APS or full-frame DSLR cameras. They work very well at increasing contrast and suppressing the glow from typical high-pressure sodium lights, though the ongoing, widespread switch to LED lighting might reduce the effectiveness of these filters in the future.

▲ **SHIELD YOUR SCOPE** Blocking stray light is an important step to improving your suburban imaging. The author went through a series of methods to block local light trespass from ruining his images, eventually settling on an ExploraDome observatory.

Narrowband filters are also available in clip-in format for DSLR cameras, but keep in mind that any of these has a one-shot color sensor, so you won't be imaging at full-resolution through a narrowband filter, and here's why. The camera's sensor uses a *Bayer filter matrix* that divides the pixels into three groups: 50% have a green filter over them, while 25% each are filtered for red and blue wavelengths, respectively. So to create a color image, each color channel must fill in the missing space between the pixels of each color (by interpolating the values nearby on the sensor), so your image will not be as high resolution as those taken with a monochrome camera with multiple exposures through single-color filters.

If you do use a DSLR or other one-shot-color camera to image under light-polluted skies, consider limiting your target choices to areas close to the zenith where gradients will be less severe. Find what works best for you and your equipment.



▲ **TACKLING GRADIENTS** *Left:* Light pollution reveals itself in this image of spiral galaxy M101 (above) as an uneven background, often appearing dark on one side of an image and bright on the opposite side. *Middle:* The gradient was isolated using the DBE tool in *PixInsight. Right:* Once removed from each color-filtered image, the results can then be stretched to reveal faint details, as seen on the facing page.

Shoot Lots of Images

Another way I improved my backyard imaging before processing my images was simply to shoot a lot of exposures. Sure, I can record my target in, say, a 3-minute exposure, but with very few exceptions it's a pretty noisy image. Our biggest goal in astrophotography is to achieve a good signal-to-noise ratio in our images, in order to bring our target out from the background sky. And under a pall of light pollution, that sky background accounts for a lot of unwanted signal, so we need lots of exposure to bring out our target. Additionally, removing light-pollution gradients from my images reduces the overall signal, so the more time I can dedicate to image-acquisition, the better my images will turn out.

I generally try to record at least 4 hours of exposure through each filter, and more when imaging through narrowband filters. I often dedicate 15 hours or more of exposure time to a single target to ensure I have adequate signal to work with. If you're imaging with a one-shot-color camera or DSLR, I suggest at least 4 hours of total exposure time, even for bright targets. The more time you invest, the better your images will be.

Individual exposures might be short, but taking many of them and stacking them together averages out sources of noise in the final while increasing the target's signal.

Speaking of individual sub-exposures, what is the optimal exposure time? That will depend on several factors, depending upon your particular camera, optics, and local light pollution. Find an online exposure calculator (like this one: **https://is.gd/DgrFMn**) to help you figure this out, though a good rule of thumb is to avoid saturating your detector.

One thing that can help me determine my exposure goal is by measuring the brightness of the sky in my backyard. A handy tool to do this is a Sky Quality Meter from Unihedron (**unihedron.com**). These devices provide unbiased reading of the sky brightness in magnitudes per square arcsecond

(MPSAS). For example, a typical, suburban night sky is about 19 to 20 MPSAS if there's no bright moonlight. For context, a pristine sky with no light pollution yields a value of 22, whereas an inner-city sky is often below 17. Knowing my sky's value helped me determine how much exposure I need for a given target. A 1-magnitude decrease in the meter's value, say from 18 to 17, means the sky brightness is 2½ times brighter. So it takes 2½ times more exposure time to get the same SNR, assuming everything else is equal.

Eliminating Gradients

Finally, once I improved my raw-image quality as much as I could, the final step in the battle against light pollution was to remove skyglow gradients from my images during post-processing. Even imaging under a dark sky produces subtle gradients that need addressing, so this step is essential no matter where I shoot.

Gradient removal is done on each stacked result but before combining into a final color image. This is perhaps the most important step to ensure a good astrophoto, because images with strong gradients are impossible to color balance. How you perform this step depends on the image-processing software you use. Most of these programs include tools to deal with gradients. I prefer the Dynamic Background Extraction (DBE) tool in *PixInsight* (**pixinsight.com**), and a helpful tutorial on using this powerful tool can be found on page 68 of this magazine's September 2014 issue.

▲ **COLORFUL RESULT** Once you address gradients in each color-filtered image stack, you can then combine the results into a dazzling result virtually indistinguishable from a shot captured at a dark-sky location.

If you're shooting with a one-shot-color camera, stack your images first. Then split the result into its red, green, and blue individual color channels; remove the gradients in each; and then recombine and color balance the result. After that, the processing steps are no different than for images taken under pristine skies.

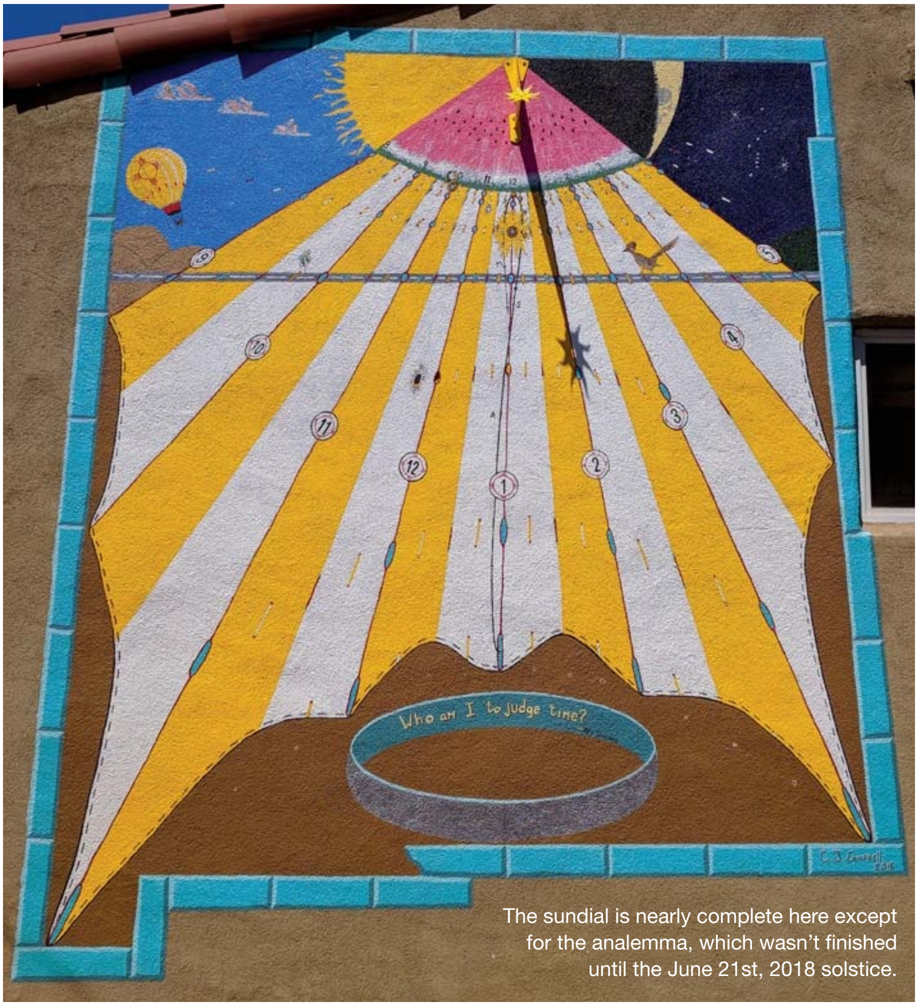
These important steps each have greatly improved the quality of my images, even from the murky glow of city lights. And it's hard to beat the convenience of shooting from home, which can open up many nights that you otherwise might have stayed indoors.

■ JONATHAN TALBOT, a retired flight meteorologist for the U.S. Air Force Reserve, spends all his free time these days imaging the night skies.

◀◀◀ **SHOOT THE ZENITH** One tried-and-true technique for mitigating the effects of light pollution in astrophotos is to target objects that pass very high in your local sky. This deep image of M33 was recorded over several nights as the galaxy passed near the zenith.

◀◀ **PUSHING THE ENVELOPE** Imaging relatively faint targets, such as the colorful object NGC 2170 in Orion seen here, is difficult but possible from urban locations. The author recorded each sub-exposure as the nebula crossed the meridian over the course of many nights.

◀ **LOTS OF SPACE** Light pollution is often easier to address in an image when the target does not fill the entire frame. This shot of M63 had strong gradients in each color channel that the author easily addressed in *PixInsight* before combining them into the color result seen here.



The sundial is nearly complete here except for the analemma, which wasn't finished until the June 21st, 2018 solstice.

▲▲ Jay marking a special moment on his sundial: the August 21, 2017 total solar eclipse.

▲ The top line of the gnomon points at Polaris, and the pointer is a Sun-disk with a hole that projects a bright spot.

JAY CAMPBELL (2); JAY ON LADDER: ELENA CAMPBELL

A Sundial Wall

Sundials can be amazingly accurate, and beautiful, too.

LAST MONTH WE LOOKED at a scale-model solar system. This month let's look at something fun you can do with the actual full-size solar system.

Sundials use the Earth's rotation, axial tilt, and orbit around the Sun to measure time. We tend to think of sundials as little birdbath-sized things that can tell you whether it's morning or afternoon, but a large one can be amazingly accurate. And there's no reason why a sundial has to be horizontal, either. New Mexico amateur Jay Campbell has created one on the side of his house.

Jay is a bit of a Sun nut, and he's also a mechanical engineer. He was very involved in the design of the Solar CooKit for Solar Cookers International (**solarcookers.org**), and he loves to check out sundials during his extensive travels around the world. "I have long admired the big public dials and noon lines throughout Europe and wanted to create one of my own," he says. "I've been tracking shadows and marking floors for many years. This is my first major sundial, but it's based on years of observing, learning, and testing."

Although they look dramatically different, horizontal and vertical sundials are very similar. The top edge of the *gnomon* (the pointy bit) needs to be aligned with the celestial pole for either type, so it's parallel to the Earth's axis. Basically, its angle from the ground is equal to the latitude where it's installed. The main advantage of a vertical dial is that it can be much larger and therefore more precise. Jay's is 10 × 11 feet (3.05 × 3.35 meters), which is large enough to show both time and date with good accuracy.

Sundials work by casting a shadow that moves as the Earth rotates. The left-right position of the shadow tells the time of day, while the length of the shadow tells the time of year. But, Jay warns, "One important thing to understand about sundials is that they are truly correct only four days each year. Due to Earth's elliptical orbit around the Sun, a dial is generally a few minutes fast or slow relative to clock time. The error goes up to about 6 minutes in the spring and summer, and up to 16 minutes in the fall and winter."

That's where the analemma comes in. That long, slender figure 8 running down the centerline is a graphical representation of the offset as the Earth speeds up and slows down in its orbit. It is, in fact, the exact position of the gnomon's pointer at clock noon. To get the correct time, you visually add or subtract the analemma's offset to the gnomon's reading at the moment. Jay reports, "I can usually get within ± one minute of clock time. It's more precise during the summer, given that the longer shadow travels about 3 times as far than in the same time in December."

Jay used an idea from an old Chinese sundial that lets sunlight through a small hole in a large disk. That way there's a big shadow with a bright spot in the middle, which makes it easy to read from a distance. Of course, Jay's shadow disk is a representation of the Sun.

Jay started the project in early June of 2017. After mounting the gnomon near the peak of his roof, he started marking points on the solstice, June 21st. At 15-minute intervals he marked the outline of the spot, and those spots became the long row of ellipses at the bottom edge of the field. Each month, on or about the 21st, he did the same thing. The equinoxes on September 22 and March 20 were the dates for the single straight line across the center. Additionally, at exactly clock noon he made another point along the analemma. Connecting those dots created the figure 8.

For the final artistic presentation, Jay chose to make the sundial represent its home: the state of New Mexico. The equinox line became Route 66, the watermelon slice is a tribute to the beautiful Sandia (Watermelon) mountains, and the whole works is framed in turquoise, New Mexico's state gem. The balloon commemorates the Albuquerque International Balloon Festival.

▲ The pointer spot illuminates one of Jay's special moments.

Jay has also marked several personal moments on his sundial. And the motto at the bottom comes from the very last line of an essay a family friend wrote before he died.

Jay has created a beautiful and highly functional work of art. You could, too!

For more information, visit Jay's website at **NewMexicoSundial.com**.

■ Contributing Editor **JERRY OLTION** is also a bit of a Sun nut, because he lives in the Pacific Northwest, where the Sun is pretty much a rumor most of the year. Contact him at **j.oltion@gmail.com**.

JAY CAMPBELL

Soft Drinks and Stargazing

Amateur Telescope Making and Popular Astronomy under Franco's Dictatorship

On the morning of July 18, 1936, Spaniards awoke to the news that a military coup had been staged against the elected leftist government of the Second Spanish Republic. It was the start of the Spanish Civil War (1936–1939), a devastating conflict that marked the beginning of one of the longest European dictatorial regimes of the 20th century. General Francisco Franco's totalitarian government (1939–1975) signified a break with the past in many political, ideological, and social aspects, including cultural expressions and intellectual traditions. An official historical narrative that justified and glorified the new regime brought significant changes from an institutional perspective, including the purge and forced exile of many Spanish scientists and scholars. Moreover, the years of hunger and misery that characterized postwar Spain were ones of intense social propaganda and mandatory recatholization. This included the practice of science, which was officially purged of foreign influence and submitted to the Catholic doctrine.

New Associations

The case of astronomy was particularly indicative of the role played by science in Spanish society in the 20th century. Astronomical discoveries and theories of the 19th century had captured the public imagination. In addition, the observation and study of the heavens was seen as a tool that could offer evidence in favor of the existence of God and the Creation, and helped humans find their place in the universe. As a result, astronomy remained fairly popular in Spain during the opening decades of the 20th century, with the number of amateur participants increasing significantly. The solar eclipses of 1900 and 1905 had generated interest in observing among a wider public, and figures such as the popular French astronomer Camille Flammarion and organizations such as the Société Astronomique de France (SAF) encouraged amateurs to pursue the hobby. In 1910, the Astronomical Society of Barcelona (Sociedad Astronómica de Barcelona, SAB) was founded to coordinate Spanish and Catalan amateur astronomers, and in 1911 the Astronomical Society of Spain developed as an offshoot of SAB. Soon to be renamed the Astronomical Society of Spain and America (Sociedad Astronómica de España y América, or SADEYA), the society encouraged

Crisis In Spanish Chaos Is Imminent

Francisco Franco Supreme Dictator Of Rightist Spain

ARMED MASSES LEAVE MADRID TO BATTLE REBELS IN PROVINCES AS SPANISH CIVIL WAR SPREADS

▲ **CRISIS AND CHAOS** The Spanish Civil War began with a coup against the Second Spanish Republic. World news agencies scrambled to document the turmoil taking over Spain and Spanish Morocco.

cooperation between amateur and professional astronomers working in Spain and the Americas. Supported and promoted by the astronomer Josep Comas i Solá, SADEYA thrived in its early years. Comas i Solá established an important program of popular astronomy in Barcelona and guided a series of public lectures, exhibitions, courses, publications, and group visits to Fabra Observatory. SADEYA played a large role in popularizing astronomy and keeping the hobby going during the dictatorship.

Severe regulations established by the dictatorial regime during the postwar years had a strong impact on the daily life of the society. SADEYA remained popular, but fresh young amateurs felt uneasy with the way the main Spanish astronomical association was organized and run by academics and

NEWSPAPER HEADLINES: *DAILY INDEPENDENT* (DECEMBER 25, 1936) / *DAILY INDEPENDENT* (OCTOBER 2, 1936) / *EVENING STAR* (JULY 21, 1936); BACKGROUND TEXTURE: PABLOHART / GETTY IMAGES senior amateurs. Despite encouraging systematic amateur work, such as the methodical observation of variable stars, SADEYA seemed unreceptive to the enthusiasm of young people. This situation led to the creation of new amateur astronomical associations in Spain during the middle decades of the century.

The founding of such nonprofessional astronomical associations is particularly interesting, since the development of amateur science, which was less dependent on the precepts of official science, was fairly difficult for the dictatorial regime to oversee. Moreover, such initiatives can be seen as attempts to develop new spaces for scientific sociability in response to the new political and socioeconomic conditions of the dictatorship. The search for valuable instructional and cultural resources provided by astronomy was combined, during these years, with the exploration of less restricted spaces for socialization sought by young people.

A good example of one of these new societies is that of the Astronomical Association Aster (Agrupación Astronómica Aster), founded in Barcelona in 1948 by a group of secondary school students. Aster eventually fostered a successful program of observational astronomy that included the study of celestial objects such as the Moon, the Sun, planets, bolides, comets, nebulae, stars, and star clusters. The association even achieved some international renown in 1957, when it became the first in Western Europe to record the signal of Sputnik 1 using only amateur techniques and equipment (an antenna and a homemade radio device). Aster, however, was not exempt from criticism, as some thought it inappropriate that the association was run by such young men. Claims were made that its founders were writing on topics they knew little about, and many people expected the new society to be transformed into a party and social club. Some individuals filed formal complaints with the authorities, denouncing the association as it was run by minors and organized activities that allegedly encouraged promiscuous behavior.

NOTAS VARIAS

La Agrupación Astronómica «Aster» inauguró su nuevo Observatorio

Ayer, al mediodía, tuvo lugar la inauguración y bendición del nuevo observatorio de la Agrupación Astronómica «Aster», instalado en el ático del inmueble número 71 del Paseo de Gracia, por el reverendo Padre Manuel Bordas, Sch. P., al que asistieron representaciones de las autoridades locales y numeroso público. La instalación consta de un refractor de 110 milímetros, «Mailhat», con montura ecuatorial, cámara fotográfica de foco corto de 35 centímetros, objetivo 1.4.5. Cabe destacar el desinteresado anhelo de esta Sociedad, que no es otro que el fomentar el conocimiento de la Astronomía en todas las clases sociales. La realización llevada a cabo es producto del esfuerzo de sus 800 socios, que, mediante su aportación económica, sin ayuda externa de otra clase, han hecho realidad sus sanas aspiraciones.

▲ **ASTRONOMICAL SUCCESS** This short bulletin, which ran in the November 30, 1953, edition of the Barcelona newspaper *Hoja del Lunes*, celebrates the dedication of Aster's new observatory, which boasted a Mailhat 100-mm refractor on an equatorial mount. The telescope was also equipped with a short-focus 33-mm camera. The dedication was attended by representatives of the local authorities as well as members of the public, and was presided over by Father Manuel Borda. The story also points out the society's "selfless desire" to promote the knowledge of astronomy to everyone regardless of social class. Aster's success in this area was attributed to the efforts and economic contributions of its 800 members.

Despite encouraging systematic amateur work, such as the methodical observation of stars, SADEYA seemed unreceptive to the enthusiasms of young people.

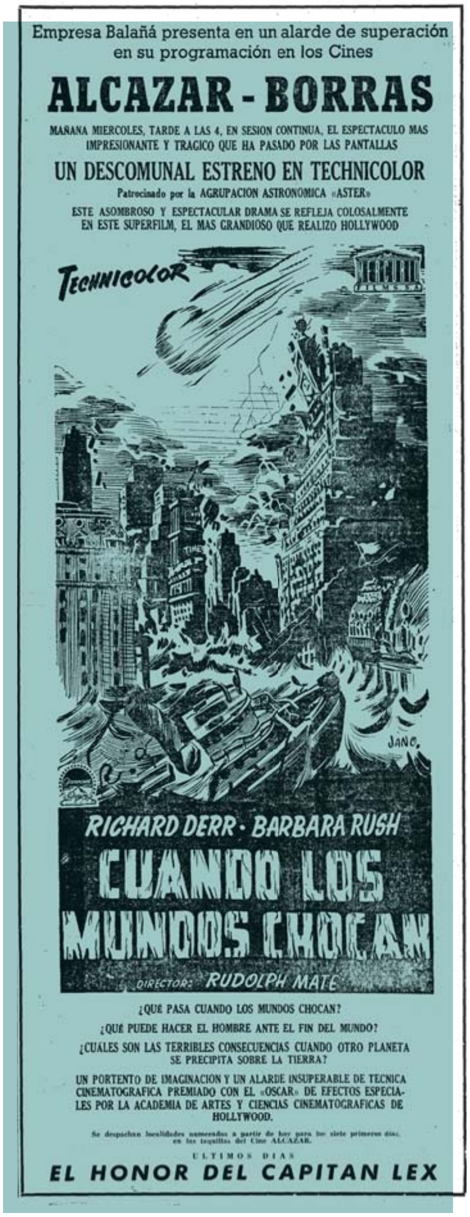
Certainly there was an element of fun to Aster. The group developed a popular astronomy program that combined lectures and courses with visits to institutional and private observatories, outdoor talks, and excursions to tourist sites. That there were private "after parties" with snacks, soft drinks, and dancing is undeniable. Critics from SADEYA believed such frivolous activities were the real goal of the group, while others, such as the Spanish popularizer of astronomy, José María Meliá Bernabéu "Pigmalión", saw enjoyable activities such as dancing and socializing as a hook: First give them soft drinks, then give them scopes. Since the youth seemed to prefer entertainment to study, Aster focused on the fun, organizing field trips, contests, and exhibitions in which pictures, books, journals, and instruments were displayed.

Telescope Making

Some of the instruments shown at Aster exhibitions were homemade telescopes, such as those made by amateur astronomer Josep Costas Gual (1918–2011), who developed an important program of systematic solar observations over

▼ **PRO-AM COOPERATION** Founded in 1904, Fabra Observatory was equipped originally with a Mailhat double refractor, which consisted of a 38-cm f/15.8 visual instrument and a 38-cm f/10.5 photographic instrument. A popular destination for field trips, the observatory continues to hold observing events in conjunction with Aster.

NEWS ARTICLE: AGRUPACIÓN ASTRONÓMICA ASTER / *HOJA DEL LUNES* (NOVEMBER 30, 1953); OBSERVATORY: PUBLIC DOMAIN / SERVEI METEOROLÒGIC DE CATALUNYA



▶ **MOVIE NIGHT** Aster tried to draw potential new members by scheduling pleasurable astronomy-themed activities, including movie screenings. This advertisement invites the public to the view the "most impressive and tragic" science fiction feature *When Worlds Collide*. As the poster suggests, the plot of the movie revolves around the impending collision of a great star (Bellus) and Earth. Humans have three months to plan for their survival. Will anyone come out of this story alive?

AGRUPACIÓN ASTRONÓMICA ASTER / LA VANGUARDIA ESPANOLA (FEBRUARY 23, 1954)

the years. In contrast to the United States, amateur telescope making (ATM) never became a mass hobby in Spain, although a significant number of amateurs like Costas contributed to the circulation of astronomical knowledge and supplied information and instruments to those interested in homemade telescopes. A founding member of the Group for the Dissemination of Astronomy of Baix Montseny (Grup Pro Divulgació Astronómica del Baix-Montseny, PDA), Costas led the charge in Spanish ATM.

Costas's early attempts to obtain satisfactory instruments spurred his interest in producing his own telescopes. The first naked-eye observations he made were soon superseded by observations using binoculars and homemade instruments — in particular, small but effective refractors made of biconvex lenses from ordinary glasses and using simple lenses as oculars. Costas worked with prisms and lenses, hoping to improve the performance of his instruments. The optical material used for such initiatives was mostly recycled from other instruments. The most notable of the instruments, named "Helio," had a 130-cm focal length and a magnification of about 60×. Slowly but surely, Costas became relatively well known in the community of amateur astronomers for making simple, good-quality, and cheap optical instruments. Indeed, several Catalan amateur astronomers placed orders for instruments.

Costas's work in the postwar years is indicative of the resurgence of earlier amateur practices and interests, including telescope making. Knowledge about ATM circulated among amateurs during these years under the influence of several initiatives developed by SADEYA and Aster. A good example of this was the establishment of an Instrument Commission by the latter, fully operational by the early 1950s, in which issues such as the production of both equatorial mounts and lenses were discussed. This organization was inspired by the commission created by the SAF to deal with the same topic. In fact, Aster's Instrument Commission had a productive exchange of information with the commission coordinated by the noted French telescope maker Jean Texereau (1919–2014), leading to the development by the mid-1950s of a 550-mm-aperture Newtonian telescope. In addition, Aster edited an illustrated leaflet, entitled *The Construction and Operation of an Amateur Telescope* (*Construcción y manejo de un telescopio de aficionado*), which explained how to make cheap telescopes with achromatic objectives.

Several Spanish amateurs attempted to produce their own mirrors in the 1940s. However, mirror grinding proved too difficult for most. The turning point came with Texereau's 1951 book *How to Make a Telescope* (*La construction du telescope d'amateur*). The publication and circulation of Texereau's work, together with the recovery and translation into Spanish of several articles published by Albert G. Ingalls (1888–1958) in *Scientific American*, had a crucial impact on Spanish amateur astronomy in the 1950s. Such a boost for ATM, promoted by astronomical societies and associations, encouraged many amateurs to produce their own low-cost telescopes, notably increasing the apertures they worked with, mostly from 60 or 110 mm to 150 mm, 200 mm, and even 300 mm.

A good example of this evolution is the work of Salvador Aguilar (1913–1988), a mechanical technician and member of Aster, who had earlier been engaged in the construction of rudimentary telescopes using glass lenses. Aguilar devoted part of his small workshop to producing mirrors following Texereau's techniques, as well as to building complete telescopes. Among his main contributions to ATM was the development of a vacuum system of aluminization that helped to overcome (for the first time in Spain) problems related to the chemical silvering of mirrors.

Such interests led SADEYA to organize a workshop in 1957 for teaching interested amateurs how to make reflector telescopes, including the mirrors. The workshop was so successful — with more than 100 attendees — that it was offered again the following year. Among the attendees of the first workshop organized by SADEYA was the lawyer and amateur astronomer Josep Maria Alfaras Castañeda (1913–1990). It was Alfaras who was responsible for convincing and helping his good friend Josep Costas to start grinding mirrors in 1961. Costas began with a piece 116 mm in diameter, and it took him more than a month to realize that he could achieve good results. Following his success, he began receiving orders from members of both SADEYA and Aster. He even began teaching his techniques in the backroom of his corner shop (a convenience store called *La Fontana de Oro*). Costas soon became one of the most respected amateur telescope makers in Spain and produced more than 3,500 parabolic mirrors for reflector telescopes; these were used by many Spanish amateurs during the second half of the 20th century.

Social Spaces and Science

These initiatives have to be understood as part of a wider program for the popularization of astronomy, since the instruments were not only suitable for amateurs to start making observations, but also encouraged small groups of amateurs to begin their own outreach activities. Indeed, they fit with Aster's efforts to popularize astronomy, which also included the projection of films and documentaries, as well as musical sessions on the flat roof of the association premises — many of them using difficult-to-find materials provided by foreign institutions such as the French and American consulates. The most popular activities were, certainly, the parties held after some of the conferences. Public parties, and especially dancing, had defined the leisure of young people in Spain for decades. Nevertheless, the dictatorial regime paid special attention to the regulation and control of public parties, particularly under the influence of the Catholic Church, which developed a campaign against dancing, mostly on moral and class-conscious grounds.

In this context, private parties such as those organized by Aster no doubt reaffirmed an autonomous youth culture that flourished during the dictatorship in spaces not directly controlled or supervised by older adults. Surprisingly, however, the creation of new amateur astronomical societies and the organization of such successful popularization programs were not seen by the dictatorial regime as dangerous or threatening. In fact, it even seemed to fit well with some of the guiding principles defended by Franco's government, such as the ideals of social harmony, cooperation, and union, as well as the glorification of youth. And many activities developed by Aster were reported and publicized by the press, radio, and Spanish newsreels. Undeniably, the observation and study of the skies could prove particularly useful for spreading the ideological values of the dictatorship.

Ironically, given the regime's determination to suppress foreign influence on Spanish science, such accomplishments were only possible thanks to an already-existing amateur tradition that had developed in Spain during the first few decades of the 20th century, particularly under the influence of Flammarion and SAF. Many amateurs, however, saw in the practice of astronomy a way to share their concerns and hopes, as well as their perception of the world. Such an exchange of ideas constituted a bastion of freedom to enjoy with others, where they could experience ways of thinking that differed from those in their respective environments. Indeed, the development of amateur astronomy in autonomous groups outside the direct control of the regime played an important role in the gradual rebuilding of Spanish civil society.


ESPAÑA Y SUS VALORES

Comas Solá y el Observatorio Fabra

Umbral 5

PUBLIC DOMAIN / *UMBRAL* (OCTOBER 2, 1937)

▲ **LIBERTARIAN SPAIN** This full-page celebration of Josep Comas i Solá and his work at the Fabra Observatory was published in 1937 under the heading "Spain and Its Values" in *Umbral*, a weekly publication printed during the Spanish Civil War in València and Barcelona. Comas, a guiding light in amateur astronomy in Barcelona, was the first director of Barcelona's Fabra Observatory.

■ **PEDRO RUIZ-CASTELL** is an Assistant Professor in History of Science at the University of València in Spain and a member of the López Piñero Institute for the History of Science and Medicine. His research and publications have focused mostly on astronomy and astrophysics in the 19th and 20th centuries, science in the public sphere, and scientific instruments.

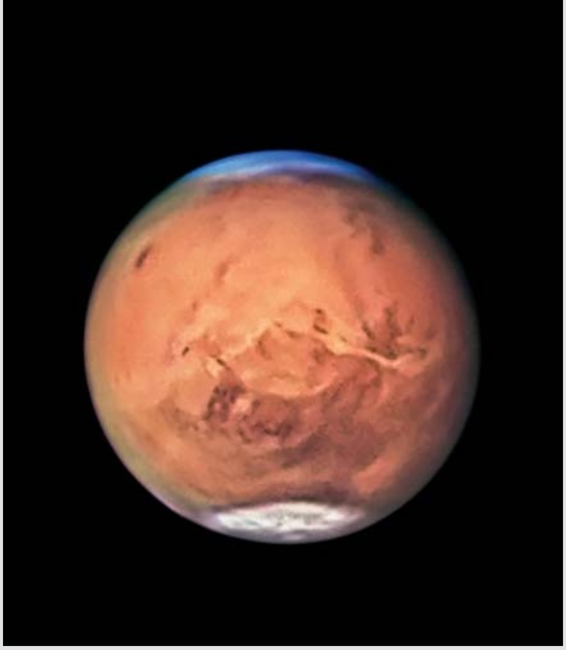
MONO TRAILS
Fabrizio Melandri
More than three hours of star trails arc above the surreal landscape at Mono Lake in California.
DETAILS: *Nikon D7000 DSLR camera with 18-mm lens at f/4. Stack of 572 20-second images recorded at ISO 1250.*

▽ OMEGA NEBULA

Gregg Ruppel

Emission nebulae Messier 17 (center) and IC 4707 (top right) are actually part of the same cloud of hydrogen gas, bisected by a dust lane that lies in front of the nebulae as seen from Earth.

DETAILS: *ASA 10N Newtonian astrograph with SBIG STL-11000M CCD camera. Total exposure: 12.8 hours through LRGB filters.*



△ DUSTY PLANET

Sebastian Voltmer

Mars displays a wealth of detail near opposition following the global dust storm that erupted in June. The Solis Lacus region is visible in the south, though dust continues to fill Valles Marineris at right.

DETAILS: *20-inch Cassegrain with ZWO ASI290MM video camera. Stacked video frames recorded through color filters on July 24 at 22:25 UT.*

BLAZING FIREBALL

Qiushi Tian

During the early morning hours of August 8th, a slow, bright bolide lit up the landscape in Ergun, Mongolia, which briefly outshone the waning crescent Moon seen behind the light post at right.

DETAILS: *Canon EOS 5D Mark III DSLR camera with 24-to-105-mm lens at f/4, ISO 6400. Total exposure: 10 seconds.*

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Meeting My Space Hero

As the 50th anniversary of Apollo 8 draws near, the author recalls a memorable moment with its command module pilot.

THE SPACE AGE BEGAN on my 20th birthday. It was October 4, 1957, when the Soviet Union launched Sputnik I, the first man-made object to orbit Earth. Little did I know then how smitten I would become with space exploration, or that one day I'd come face to face with my astronaut superstar.

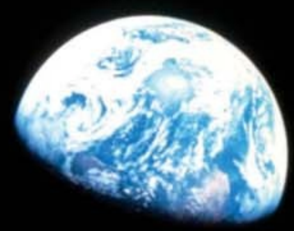
Dramatic missions followed Sputnik in dizzying succession, and from my home in Israel I followed them all with great interest: the first dog in orbit, the first man, the first spacewalk. The next big goal, it was clear, would be to reach the Moon. That happened on September 13, 1959, at least vicariously, when Luna 2 struck our satellite and became the first man-made object to land on another world. All these missions scored the Soviets huge propaganda victories.

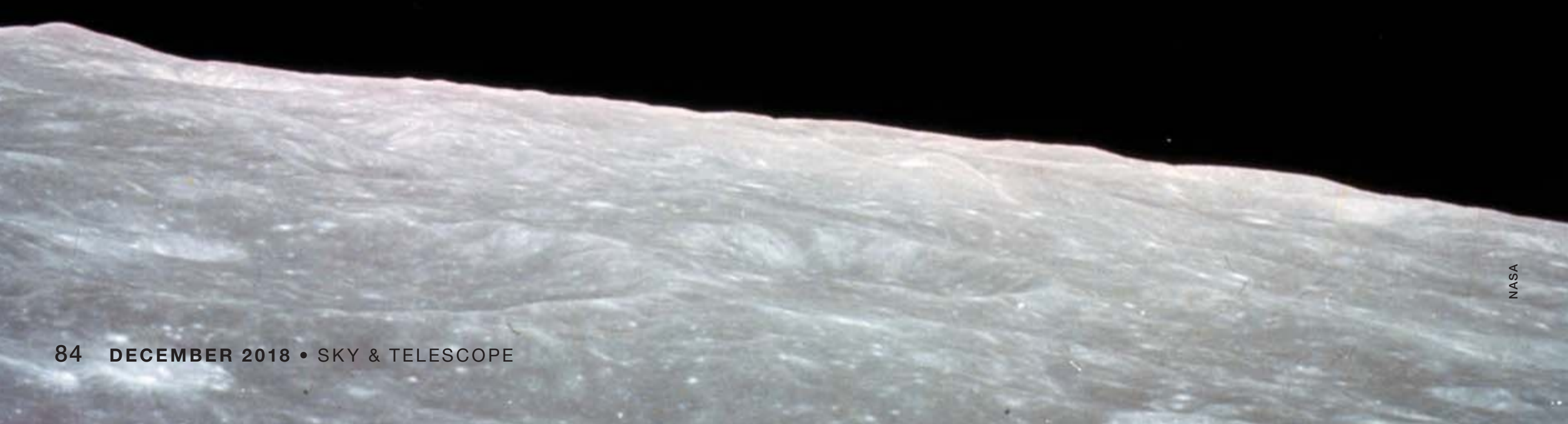
Not about to be left behind, on May 25, 1961, President John F. Kennedy announced his goal of sending an American to the Moon before the end of the decade and bringing him safely back. The race of the century was on.

Now fast-forward to December 1968 — 50 years ago this month. Just one year remained before Kennedy's deadline would expire. Apollo 8, at first planned as an Earth-orbiting mission to test the giant new Saturn V rocket, was launched instead to the Moon on December 21st in a desperate effort to beat the Soviets.

Frank Borman, Jim Lovell, and Bill Anders thus became the first humans to arrive at another world. Their outbound trip took a little more than two days, not much longer than Charles Lindbergh's historic New York-to-Paris flight 41 years before. They orbited the Moon ten times and were the first humans to see its farside, "a big heap of crater upon crater," as Anders described it.

Just over a year later, Lovell commanded the ill-fated Apollo 13. An explosion on their outbound trip caused the cancellation of what would have been the third manned landing on the Moon. Lovell thus became the only person to fly there twice and not make a landing.





The iconic photo from Apollo 8: Bill Anders's shot of Earthrise, taken on the mission's fourth orbit of the Moon.

NASA

What's a man to do after such a crushing disappointment? The ever-cheerful Lovell opened a restaurant in Lake Forest, a quiet Chicago suburb. In 2006 my wife Dalia and I had lunch there. Not long after we were seated, Lovell came over to our table. When I told him that everyone in Israel had prayed for Apollo 13's safe return, he appeared visibly moved.

It was the second time I'd met him, actually. The first was in 1995 at Chicago's Museum of Science and Industry, where he'd inscribed a copy of his book *Lost Moon* (written with Jeffrey Kluger) to Dalia and me; it remains one of my most precious mementoes. At the book signing, Lovell was sitting in front of the charred Apollo 8 command module that had carried him and his crew around the Moon and returned them safely to Earth.

Whenever I experience a setback in life — and who doesn't? — I find myself thinking of Jim Lovell and how he coped with his lost Moon. We're blessed that, half a century after their historic mission, all three Apollo 8 astronauts remain with us. May we have them many more years yet.

■ **ELI MAOR** has written seven books on the history of mathematics and astronomy. He and his wife split their time between Chicago and Jerusalem.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